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THE ROLE OF ELECTRONICS IN NATIONAL SURVIVAL*

BY

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Mr. Chairman, Ladies and Gentlemen: being invited to address this distinguished gathering is a great honor and privilege. I heartily welcome this opportunity to discuss the importance of electronics to our national security with you people who are active in the various fields of science and engineering.

My topic is one of vital interest to every American. It is also a subject that is generally not too well understood or appreciated. We hear and read a lot these days about national survival and the strength of our military forces. But most of it concerns such things as ballistic missiles, bomber aircraft, nuclear-powered submarines and satellites. We hear very little about the fact that the successful operation of all these weapons and systems critically depends upon electronic devices and systems of fantastic complexity and precision—devices and systems, that, in almost every case, have pushed electronic technology to the limits of the state of the art and sometimes beyond. This evening I want to tell you a little more about defense electronics and its significance in our endeavor to maintain a military strength sufficient to deter communist aggression.

Perhaps the best measure of electronics' importance in defense is the amount of national effort and defense dollars being spent in this area. The military departments are currently spending around $6 billion a year for electronics research, development, engineering and produc-

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tion—well over one-half the total national output of our great electronics industry and almost one-quarter of the total defense expenditure for all research, development, engineering and production. Even more significant is the fact that approximately 40 per cent of all military RDT & E (Research, Development, Test and Evaluation) funds is now going into the area of electronics. This tremendous military research and engineering effort employs around 80 per cent of all the electronics scientists and engineers in this country.

Obviously I haven't time to describe, or even list, the hundreds of different research and development programs that make up this vast national effort in electronics research and engineering—for instance, radar, infrared, computers, communications, acoustics, inertial guidance and electronic components. Nor can I take time to explain the vital part played by electronics in each of our modern military weapons and systems. Instead, let me give just a few specific examples illustrating how critically the success of our military operations depends on electronics.

The development of the NIKE–ZEUS anti-ballistic missile defense system provides a good illustration. I suspect that most people realize that difficult technical problems are involved in producing a missile with the range, speed, maneuverability and lethality it must have to intercept and destroy an ICBM warhead entering the atmosphere at perhaps twenty times the velocity of sound. But I doubt that many recognize that the complex and challenging problems of the missile's design are dwarfed by the technological difficulties involved in developing the radars and computers and the other electronic control devices required to make the NIKE–ZEUS effective.

The development of these major electronic systems, having the range capabilities, precision and speed of operation that will enable the weapon system to detect the warhead, identify it among the decoys and rocket fragments, track it accurately, solve the fire-control problem and direct the missile to an accurate interception—all in a very few short seconds—presents one of the most difficult research and engineering tasks ever undertaken in any technological area. The problem's magnitude and complexity can be seen from the fact that there are some half-million active semiconductor devices in the electronic equipments making up a single NIKE–ZEUS defense center. It is a shocking realization when we compare this system with its fantastic number of active electronic components with the antiaircraft fire-control systems of 15 years ago that, with only 500 vacuum tubes, were considered fearfully complex or even with the most modern surface-to-air anti-aircraft missile system, which has about 2,000 active electronic elements.

The intercontinental ballistic missile is also typical of modern weapons', absolute reliance on electronics. It is hard to imagine that a huge nuclear warhead can be projected across 8000 miles of the Earth's

surface and hit a target well within two miles of the aiming point. This represents an angular accuracy approaching one hundredth of a degree and a range precision better than three thousandths of one per cent. This remarkable guidance by the electronic sensing and computing elements in the missile and at the launcher represents one of the most advanced and sophisticated applications of electronics technology; it took thousands of man years of scientific and engineering effort to develop.

In another weapons area, the B-70 manned bomber will contain the most advanced and complex array of electronic devices ever assembled in an aircraft. It has been estimated that the development and engineering of the bombing-navigation system alone will cost close to a quarter of a billion dollars and will require 8000 to 10,000 man years of engineering. This is only one of the major electronic subsystems this advanced aircraft weapon system will need to perform its mission.

Probably the most exacting use of electronics in our whole defense program is in space developments. Certainly a space system depends more completely upon electronics than any other in civilian or military use. Once a rocket carrying a satellite into orbit leaves the launching pad, only by means of electronics can we obtain information from the space vehicle, whether it concerns the vehicle's precise location or data acquired by its various sensing instruments, most of which are themselves complex electronic devices.

In one of our current military space programs, the satellite carries equipment employing some 28,000 electronic parts—about equivalent to 100 home television receivers. To be operationally and economically feasible, this complicated equipment must operate satisfactorily in space, with no adjustment or maintenance, for long periods of time, perhaps a year or more. Can you imagine turning on 100 television sets and letting them run continuously for a year without having to adjust one set or replace a single defective part? Attaining reliability of electronic equipment that is essential for space applications poses a tremendous engineering problem. It will call for the development of electronic components and construction techniques that are far more reliable than those available today.

I hope these few examples make it fairly clear that electronics is the keystone of our military capability and, in most cases, the controlling technology.

Now I would like to mention the critical and urgent need for more rapidly advancing electronics technology across the board. This we must do to acquire the new electronic concepts, components and techniques we need for the development of new weapons and space systems so advanced and so powerful that they will give us an undeniable—and, we hope, discouraging lead over the Soviet.

Certainly I need not belabor the point that we must maintain such a

position of military and technological superiority over the communist nations. From the time Mr. Khruschchev scuttled the Summit meeting until recently, when he "declared war" on the United Nations, world events have clearly demonstrated that the only factors that might cause the communist powers to alter the frightening course of their drive toward world domination are the military strength and technological achievements of the United States and its allies.

Today the balance of military strength is in our favor. Both the President and the Secretary of Defense have said repeatedly that this nation has the most powerful military force the world has ever known—one that is not second best to the U.S.S.R. or any other nation. I firmly believe that this is so, although I realize that in certain force postures the lead is marginal. Certainly if we are to stay ahead, we must continue to develop, produce and deploy our weapons at an ever-increasing pace. But just staying ahead is not enough. In the critical years ahead, we must strive to create entirely new kinds of weapons based on new technology—weapons that will give the West a decisive military advantage. I am not speaking of weapons that merely evolve through refinement and gradual improvement of existing weapons but, rather, of radically new ones that can significantly change the balance of power in our favor. What sort of weapons these new ones will be, I cannot say, the atomic bomb was one; the ICBM was another.

Now why do I feel that future breakthroughs in weapons are so important? Very pertinent to this is the situation I see developing in the major strategic forces that constitute our deterrent and retaliatory power, which is so vital to our national survival. Our powerful strategic striking force of manned bombers, an extremely important part of our deterrent strength, is currently undergoing a rapid transition. It is being complemented by a family of intercontinental ballistic missiles: the ATLAS is now operational, the submarine-launched POLARIS is entering the Navy's operational forces this fall, and the TITAN will be added to our operational ICBM forces the middle of next year. In addition, the development of MINUTEMAN, which has a shorter reaction time, greater reliability and better performance than ATLAS, is being developed on an accelerated schedule.

With this rapid expansion of ICBM strength, both in the United States and the U.S.S.R., it seems obvious to me that, unless disarmament negotiations are successful, there will develop within a very few years a balance of deterrent strength between the Communist and Western powers that will constitute a deadly and frightening stalemate of missileborne destructive power. Each side will have a sufficient number of these missiles—dispersed, hidden and protected by site hardening—for a potentially complete mutual destruction, even on a "strike second" basis. When such a weapon stalemate exists, it seems most unlikely that any nation would start an all-out thermonuclear war.

Although these supersaturated forces of destruction probably constitute an excellent deterrent to nuclear attack on this country—and, incidentally, provide a tremendous incentive for the negotiation of world disarmament—it does not appear that they will significantly deter the outbreak of limited wars. It is inconceivable that any nation would risk almost certain destruction of its civilization by employing such forces in limited military conflicts. This means that our tremendous investment in bombers and intercontinental ballistic missiles will probably not keep the Soviet from continuing to nibble away, even using military force, at its long-range objective of world communism.

But, if we could definitely break this growing deterrent stalemate by acquiring some radically new weapons that would give us an overwhelming military advantage, we could not only deter all-out attack against us but might discourage continued aggression on a limited scale.

One thing that could break the balance of deterrent forces would be a truly effective system of defense against them—not one that would merely stimulate the opposition to build and deploy more missiles in an effort to re-establish the balance, but a defense system, including fall-out shelters, that could effectively protect our military, industrial and population centers against a massive, all-out attack. Almost surely the nation that first achieves such a defense would have a tremendous military and political advantage, at least until methods of countering the defense were developed or until both sides had equally effective defenses.

This discussion of total defense against ballistic missiles illustrates my point concerning the potential importance of radically new weapons based on new technology. Obviously, this is only one area where such new weapons could exert a significant and, perhaps, decisive influence on the balance of power between East and West.

In tactical warfare radically new weapons could also be extremely valuable. As I said before, it is unlikely that our strategic thermonuclear forces will prevent aggressive acts of a limited nature on the part of the communists. It is essential, therefore, that the tactical forces of our Army, Navy and Air Force be kept always at the highest possible level of efficiency. To this end, these forces should have ready to use the most advanced weapons that our scientists and engineers can provide.

Also in the area of command and control we urgently need new systems based on new concepts and new techniques. The requirements for reliability, capacity and reaction times in command and control have advanced so rapidly with the growth of weapon capabilities that current computer and communications technology is not fully adequate to meet these system needs.

Our space programs also demand electronic components and techniques that we do not have at present. I am not just sure where space

activities fit into the involved picture of competition for world supremacy. It is evident that satellites orbiting the Earth have great potentialities for military use in communications, navigation, warning and surveillance and various defense agencies are vigorously pursuing extensive programs in these areas. Probably other space ventures—putting "man in space," probing the moon or planets or embarking on journeys beyond our own solar system—will profoundly affect our national prestige throughout the world. But the military implications of these ventures are not clear. Still we cannot afford to shut our eyes to these programs, nor to the revolting possibility that space—even outer space—may some day represent another dimension of man's battlefield. It is conceivable, for example, that space systems apart from the provision of early warning, might play an important role in establishing a fully effective defense against ballistic missiles such as I mentioned earlier. I just don't know how these things will develop—and I am not sure that anyone else knows.

To reiterate the point I have been making for the past few minutes: Radically new weapons and systems can profoundly and, perhaps, decisively influence the balance of power between the communist and free worlds. Indeed it is entirely possible that a single fundamentally new weapon could be the determining factor in our civilization's survival in the coming decades. But any such weapon will almost certainly come out of new technology rather than refinements based on current weapon approaches. Accordingly, I consider it imperative that this nation shift an appreciable amount of its scientific and engineering resources from the task of developing generation after generation of weapons that only marginally increase our total strength to the task of research and technical development on which to base the new concepts and new techniques—and, possibly, the technological breakthroughs—that will make possible the development of decisive new weapons.

Since electronics is now the most important single technology in weaponry, it is clear to me that this area should encompass the greatest expansion of this fundamental technological effort. I would expect to see in the broad area of electronics some of the great technological advances and breakthroughs that will impact significantly on our future military capability. I can't foresee what those breakthroughs will be, nor when they will occur, nor what effect they will have on the balance of world power. I *can* say, however, that throughout the country some pretty exciting things are going on in electronics research laboratories. Here are some of them: The generation and amplification of coherent light; computers that can learn and possibly "think"; microwave generators with outputs measured in megawatts of average power; thermionic power conversion, new methods of radio transmission wherein all system elements, including the antenna, are hundreds of

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feet below the Earth's surface; and revolutionary concepts of solid state and cryogenic electronics that may make it possible to house in the limited volume of a space vehicle a computer with the capability of the SAGE system. Some of the many new avenues of electronics research now opening up may hold the secret of a new force that could give us the desired unchallengeable lead over communism.

But, unless we put more national emphasis on research and exploratory development in electronics—and I want particularly to stress the need for additional emphasis on exploratory development—these and other promising technological advances in electronics will be far too long coming to fruition. It is not enough to expand our storehouse of knowledge through a broadened and accelerated program of fundamental research. We must carry out the applied research or exploratory development that is necessary to prove that it is feasible to apply this new knowledge to some new weapon concept. Otherwise, it may remain in the archives of scientific literature unused, perhaps forgotten by the developers of weapon systems, that is, unless it is found and used by the Soviet.

Now let me summarize the points I have attempted to bring out this evening.

First, electronics is probably the most important and most critical area of technology affecting the development of all weapons and command and control systems.

Second, our future military strength and, perhaps, our national survival may depend upon weapons that are radically new and are based on advanced or new technology rather than weapons that are mainly "warmed-over" versions of weapons now in existence or well along in development.

Third, there is an urgent need to shift a substantial portion of our scientific and engineering resources from weapons development to research and particularly to exploratory development.

Finally, because electronics is so widely used in all military weapons and control systems, a major technological advance in this area may lead to a new weapon concept that will give this country a decisive military advantage.

In closing, I would like to say that I hope and pray—as I am sure most Americans do—that a way can be found at the conference table to solve the grave problems at the root of world tension. If the contest in weapons development continues between two nations so rich in industrial and scientific resources as the U.S. and the U.S.S.R., the result will be not only a persistent and increasing drain on our civilian economy, in both dollars and scientific manpower, but a steady increase in the danger of world-wide destruction.

Speaking in Syracuse four years ago, I expressed the hope that the challenge to all mankind to conquer space would be so great that his

desire to fight among his own kind would disappear. I am afraid this was merely wishful thinking. In reality, the space programs of the United States and the U.S.S.R. have had the effect of intensifying international rivalry rather than stimulating cooperative endeavors in scientific exploration.

We must keep hoping for, and working toward, a political or sociological kind of breakthrough that will lead to permanent peace among the great powers of the Earth. At the same time, we must seek the technological breakthroughs that will enable us to keep our armed services strong enough to deter military aggression on all fronts until it is possible to bring about the disarmament of nations in a safe and generally acceptable manner.

MEASURING AMPLITUDE AND PHASE

BY

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ABSTRACT

Numerical methods for determining amplitude and phase of moderately wide band noise and noise contaminated by extraneous noise are studied. It is shown that amplitude and phase can be determined from a pair of finite moving averages on the sample noise record. Explicit expressions for such finite moving averages are given.

I. SUMMARY

A narrow band stationary noise has the appearance of a sine wave of, roughly, the midband frequency whose amplitude fluctuates irregularly, the rapidity of fluctuation being of the order of the band width. For such a noise, instantaneous amplitude and phase are readily observed or measured. Essentially, amplitude is given by the height of the record and phase by the accumulated number of cycles starting from a given time. For moderately wide band noise or for noise contaminated by extraneous noise, amplitude and phase are not easily discerned. The methods described in the paper were developed to measure amplitude and phase in such cases. Such methods were needed in practice to determine amplitude and phase of radio star scintillation data.

The (sampled) data collected constitute a (finite) sequence $x_1, x_2, \cdots, x_N$. It is assumed that this finite sequence is a random sample of length N from a weakly stationary discrete parameter process X_k, $k = -\infty, \cdots, \infty$ with mean zero. The process X_k has the spectral representation

$$X_k = \int_0^\pi \cos k\omega dU(\omega) + \sin k\omega dV(\omega), \quad k = -\infty, \cdots, \infty. \tag{1}$$

There is some question as to how "instantaneous" amplitude and phase should be defined. The following definition is used in the paper:

Let Y_k be the Hilbert Transform of X_k, that is,

$$Y_k = \int_0^\pi (-) \cos k\omega dV(\omega) + \sin k\omega dU(\omega). \tag{2}$$

Let

$$X_k + iY_k = R_k e^{i\phi_k}. \tag{3}$$

Then

$$\begin{aligned} R_k &= \text{instantaneous amplitude,} \\ \phi_k &= \text{instantaneous phase.} \end{aligned} \tag{4}$$

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Initially, say at $k = 0$, ϕ_0 is defined so that $0 \leq \phi_0 < 2\pi$. Subsequent ϕ_k are defined so that $-\pi < \phi_k - \phi_{k-1} \leq \pi$. Ambiguities mod 2π are thus removed. Consider now the finite moving average processes.

$$\tilde{X}_k = \sum_{s=-m}^{m} a_s X_{k+s}, \qquad \tilde{Y}_k = \sum_{s=-m}^{m} b_s X_{k+s}. \tag{5}$$

Define $\tilde{R}_k$ and $\tilde{\phi}_k$ by

$$\tilde{R}_k e^{i\tilde{\phi}_k} = \tilde{X}_k + i\tilde{Y}_k. \tag{6}$$

The paper discusses methods of determining the constants a_s and b_s in Eqs. 5 so that $\tilde{R}_k$ and $\tilde{\phi}_k$ approximate R_k and ϕ_k, respectively.

II. A DIGITAL AMPLITUDE AND PHASE METER

The (sampled) data collected constitute a (finite) sequence $x_1, x_2, \cdots, x_N$. It is assumed that this finite sequence is a random sample of length N from a weakly stationary discrete parameter process X_k, $k = -\infty, \cdots, \infty$ with mean zero. It is further assumed that the sampling rate is such that aliasing effects are negligible, so that the properties of the continuous parameter process can be inferred from the discrete parameter (sampled) process.

The process X_k has the spectral representation

$$X_k = \int_0^\pi \cos k\omega dU(\omega) + \sin k\omega dV(\omega), \quad k = -\infty, \cdots, \infty, \tag{7}$$

where

$$\begin{aligned} EdU(\omega) &= EdV(\omega) = 0, \\ E[dU(\omega)]^2 &= E[dV(\omega)]^2 = s(\omega)d\omega, \\ EdU(\omega)dU(\omega') &= 0 = EdV(\omega)dV(\omega') \text{ if } \omega \neq \omega', \end{aligned} \tag{8}$$

and

$$EdU(\omega)dV(\omega) = 0.$$

In the above expressions E denotes the expectation operator and $s(\omega)$ the spectral density of the process.

There is some question as to how (or perhaps if) "instantaneous" amplitude and phase should be defined. The following definition is used here:

Let

$$Y_k = \int_0^\pi (-)\cos k\omega dV(\omega) + \sin k\omega dU(\omega), \tag{9}$$

and

$$X_k + iY_k = R_k e^{i\phi_k}. \tag{10}$$

Then

$$\begin{aligned} R_k &= \text{instantaneous amplitude,} \\ \phi_k &= \text{instantaneous phase.} \end{aligned} \tag{11}$$

Initially, say at $k = 0$, ϕ_0 is defined so that $0 \leq \phi_0 < 2\pi$. Subsequent ϕ_k are defined so that $-\pi < \phi_k - \phi_{k-1} \leq \pi$. Ambiguities mod 2π are thus removed. It is tacitly assumed that the process X_k is such that this method of eliminating ambiguities is the natural one, that is, that the sampling rate is such that Prob $(|\phi_k - \phi_{k-1}| > \pi)$ is negligibly small.

Consider now the two dimensional vector process

$$\begin{aligned} X_k &= \int_0^\pi \cos k\omega dU(\omega) + \sin k\omega dV(\omega) \\ Y_k &= \int_0^\pi (-)\cos k\omega dV(\omega) + \sin k\omega dU(\omega). \end{aligned} \tag{12}$$

The spectral density matrix of the $[X_k, Y_k]$ process is

$$S(\omega) = \begin{bmatrix} 1 & i \\ -i & 1 \end{bmatrix} s(\omega). \tag{13}$$

Consider also the finite moving average process

$$\tilde{Y}_k = \sum_{s=-m}^{m} a_s X_{k+s}. \tag{14}$$

The spectral density matrix of the $[X_k, \tilde{Y}_k]$ process is

$$\tilde{S}(\omega) = \begin{bmatrix} 1 & f(\omega) \\ \overline{f(\omega)} & |f(\omega)|^2 \end{bmatrix} s(\omega) \tag{15}$$

where

$$f(\omega) = \sum_{s=-m}^{m} a_s e^{is\omega}. \tag{16}$$

The question of determining a finite moving average process $\tilde{Y}_k$ which is in some sense a good approximation to the Y_k process is discussed below. Once a suitable $\tilde{Y}_k$ process is determined,

$$\tilde{R}_k e^{i\tilde{\phi}_k} = X_k + i\tilde{Y}_k \tag{17}$$

is used to determine $\tilde{R}_k$ and $\tilde{\phi}_k$ the approximations to R_k and ϕ_k, respectively.

Minimum Variance Estimation of Y_k

One criterion for choosing a finite moving average process $\hat{Y}_k$ which is a good approximation to Y_k is to determine the constants a_s, $s = -m, \cdots, 0, \cdots, m$ so that

$$E(Y_k - \hat{Y}_k)^2 = E(Y_k - \sum_{s=-m}^{m} a_s X_{k+s})^2 = \text{Minimum.} \qquad (18)$$

On setting the partial derivatives of (18) with respect to the a_s equal to zero, the constants a_s which minimize (18) satisfy the Least Squares Equations

$$E(Y_k - \sum_{s=-m}^{m} a_s X_{k+s}) X_{k+s'} = 0 \qquad s' = -m, \cdots, 0, \cdots, m. \qquad (19)$$

Since

$$EX_{k+s}X_{k+s'} = \rho_{xx}(s - s') \equiv \int_0^\pi \cos(s - s')\omega s(\omega) d\omega \qquad (20)$$

and

$$EY_k X_{k+s'} = \rho_{yx}(s') \equiv -\int_0^\pi \sin s'\omega s(\omega) d\omega$$

the Least Squares Equations (19) become

$$\sum_{s=-m}^{m} \rho_{xx}(s - s')a_s = \rho_{yx}(s') \qquad s' = -m, \cdots, 0, \cdots, m. \qquad (21)$$

It should be noted that the determination of the constants a_s requires that the spectral density $s(\omega)$ or equivalently that the covariance functions ρ_{xx} and ρ_{yx} be known, and that the constants are in general different for different spectral densities. That is, of course, as it should be since the constants are being optimally tailored to the statistical properties of the X_k process. Thus, if the spectral density $s(\omega)$ is known and m is not too large, the constants a_s can be determined from the linear equations (21). For large m using Eqs. 21 to determine the constants a_s becomes impractical. For such cases it may be possible to obtain a close approximation to the solution of the minimization problem posed by Eq. 18 as follows:

From Eq. 12

$$Y_0 = -\int_0^\pi dV(\omega). \qquad (22)$$

What are the constants a_k that make

$$Y_0 = \sum_{k=-\infty}^{\infty} a_k X_k \qquad (23)$$

hold identically, that is, hold for every process X_k? From Eqs. 12, 22 and 23

$$\int_0^\pi \Big(\sum_{k=-\infty}^{\infty} a_k \cos k\omega\Big) dU(\omega) + \Big(\sum_{k=-\infty}^{\infty} a_k \sin k\omega\Big) dV(\omega) = -\int_0^\pi dV(\omega). \quad (24)$$

For Eq. 24 to hold identically, the constants a_k must satisfy

$$\begin{aligned} \sum_{k=-\infty}^{\infty} a_k \cos k\omega &= 0, \\ \sum_{k=-\infty}^{\infty} a_k \sin k\omega &= -1 \qquad \text{for} \qquad 0 < \omega < \pi. \end{aligned} \quad (25)$$

The (unique) constants a_k satisfying Eqs. 25 are

$$a_{-k} = -a_k \quad (26)$$

with

$$a_k = \frac{-1 + \cos k\pi}{\pi k}, \qquad k = 1, 2, \cdots.$$

Thus,

$$Y_0 = \frac{2}{\pi}\left[(X_{-1} - X_1) + \frac{X_{-3} - X_3}{3} + \frac{X_{-5} - X_5}{5} + \cdots\right] \quad (27)$$

and from stationarity

$$Y_k = \frac{2}{\pi}\left[(X_{k-1} - X_{k+1}) + \frac{X_{k-3} - X_{k+3}}{3} + \frac{X_{k-5} - X_{k+5}}{5} + \cdots\right]. \quad (28)$$

For large m the constants appearing in Eq. 28 should be a good approximation to the optimal constants, that is,

$$\hat{Y}_k = \frac{2}{\pi}\left[(X_{k-1} - X_{k+1}) + \frac{X_{k-3} - X_{k+3}}{3} + \cdots + \frac{X_{k-m} - X_{k+m}}{m}\right]. \quad (29)$$

Note that this $\hat{Y}_k$ does not depend on the underlying spectral density $s(\omega)$ of the X_k process and hence should be regarded as some sort of asymptotic result. An improved approximation (making use of the spectral density $s(\omega)$) can be obtained by employing Wiener methods, "Extrapolation, Interpolation, and Smoothing of Stationary Time Series." From Eq. 28 one notes that Y_k is given *exactly* as an infinite linear combination of the X_k. On the other hand, $\hat{Y}_k$ is only allowed to depend on a finite number of the X_k. Consider the Wiener prediction problem of predicting X_{k+m+j} from the *infinite* past $X_{-\infty}, \cdots, X_{-m+k}, \cdots, X_k, \cdots, X_{k+m}$. Assuming that this problem is solved the

best predictor is given by

$$\hat{X}_{k+m+f} = \sum_{r=-\infty}^{m} C_{f,k+r} X_{k+r}, \qquad f = 1, 2, \cdots, \infty. \tag{30}$$

Similarly, the best estimator of $\hat{X}_{k-m-f}$ from the infinite future $X_{k-m}, \cdots, X_k, \cdots, X_{k+m}, \cdots, X_\infty$ is given by

$$\hat{X}_{k-m-f} = \sum_{r=-m}^{\infty} C_{-f,k+r} X_{k+r}, \qquad f = 1, 2, \cdots, \infty. \tag{31}$$

(The problem of estimating the past from the infinite future is identical to the problem of predicting the future from the infinite past. The two solutions expressed by Eqs. 30 and 31 are thus, apart from the complexities of subscripts, the same.) Since m is large it is reasonable to take

$$\hat{X}_{k+m+f} \approx \sum_{r=-m}^{m} C_{f,k+r} X_{k+r}, \quad f = 1, 2, \cdots, \infty \tag{32}$$

and

$$\hat{X}_{k-m-f} \approx \sum_{r=-m}^{m} C_{-f,k+r} X_{k+r}, \qquad f = 1, 2, \cdots, \infty. \tag{33}$$

Finally, from Eqs. 28, 32 and 33

$$\hat{Y}_k = \frac{2}{\pi}\left[(X_{k-1} - X_{k+1}) + \frac{(X_{k-3} - X_{k+3})}{3} + \cdots + \frac{(X_{k-m} - X_{k+m})}{m}\right] + \frac{2}{\pi}\left[\frac{(\hat{X}_{k-m-2} - \hat{X}_{k+m+2})}{m+2} + \frac{(\hat{X}_{k-m-4} - \hat{X}_{k+m+4})}{m+4} + \cdots\right]. \tag{34}$$

Clearly, the $\hat{Y}_k$ expressed by Eq. 34 is only a linear combination of $X_{k-m}, \cdots, X_k, \cdots, X_{k+m}$. The [ˆ] term in Eq. 34 can be thought of as a correction to Eq. 29.

The Wiener method of obtaining an optimal predictor using the infinite past requires that an analytic expression for the spectral density be given. Generally speaking, the Wiener method of solution involves factoring the spectral density function in a certain way.

Example: Autoregressive Process:

An autoregressive process has a spectral density $s(\omega)$ of the form

$$s(\omega) = \frac{1}{2\pi} \cdot \frac{1}{\left|\sum_{j=0}^{p} b_j e^{-ij\omega}\right|^2}. \tag{35}$$

The constant $b_0 \neq 0$ and the polynomial $\sum_{j=0}^{p} b_j z^j$ cannot vanish when $|z| = 1$. One can assume, with no loss of generality, that all roots of the polynomial have modulus greater than one. For the autoregressive process an explicit solution to the Wiener prediction problem of predicting X_{k+m+1} from the infinite past $X_{-\infty}, \cdots, X_{-m+k}, \cdots, X_k, \cdots, X_{k+m}$ is known. The best predictor is, in such a case, given by[2]

$$\hat{X}_{k+m+1} = -\frac{1}{b_0} \sum_{r=m-p+1}^{m} b_{m-r+1} X_{k+r}. \tag{36}$$

The predictors $\hat{X}_{k+m+f}$ for $f > 1$ can be obtained from Eq. 36 by iteration. One notes that the best predictors $\hat{X}_{k+m+f}$ involve only the finite past. In particular, the best predictors $\hat{X}_{k+m+f}$ involve only the random variables $X_{k-m}, \cdots, X_k, \cdots, X_{k+m}$ if $p \leq 2m + 1$. The best estimator $\hat{X}_{k-m-1}$ of the past X_{k-m-1} from the infinite future is similarly

$$\hat{X}_{k-m-1} = -\frac{1}{b_0} \sum_{r=m-p+1}^{m} b_{m-r+1} X_{k-r}, \tag{37}$$

and the estimators $\hat{X}_{k-m-f}$ for $f > 1$ are obtained from Eq. 37 by iteration. Again, if $p \leq 2m + 1$ the best estimators $\hat{X}_{k-m-f}$ involve only the random variables $X_{k-m}, \cdots, X_k, \cdots, X_{k+m}$. Thus, in the case of an autoregressive process of order $p \leq 2m + 1$ the approximations (32) and (33) are exact and, consequently, the $\hat{Y}_k$ given by Eq. 34 satisfies Eq. 18 and is the Minimum Variance Estimator of Y_k.

Consider as an illustrative example the special case $p = 1$. Take b_0 and b_1 real. Then, from Eq. 35

$$s(\omega) = \frac{1}{2\pi} \cdot \frac{1}{|b_0 + b_1 e^{-i\omega}|^2} = \frac{1}{2\pi} \cdot \frac{1}{b_0^2 + b_1^2 + 2b_0 b_1 \cos \omega}. \tag{38}$$

Also, from Eq. 36

$$\hat{X}_{k+m+1} = r X_{k+m} \tag{39}$$

where $r = -(b_1/b_0)$. Thus, by iteration

$$\hat{X}_{k+m+f} = r^f X_{k+m}, \qquad f = 1, 2, \cdots. \tag{40}$$

Similarly,

$$\hat{X}_{k-m-f} = r^f X_{k-m}, \qquad f = 1, 2, \cdots. \tag{41}$$

Thus,

$$\frac{2}{\pi} \sum_{j=1}^{\infty} \frac{\hat{X}_{k-m-2j} - \hat{X}_{k+m+2j}}{m + 2j} = \frac{2}{\pi} \left(\sum_{j=1}^{\infty} \frac{r^{2j}}{m + 2j} \right) (X_{k-m} - X_{k+m}). \tag{42}$$

[2] Refer to Grenander and Rosenblatt, reference 2 in the Bibliography appended to this paper.

The series

$$\sum_{j=1}^{\infty} \frac{r^{2j}}{m+2j} = \frac{1}{2r^m} \ln\left(\frac{1+r}{1-r}\right) - \left[\frac{1}{m} + \frac{1}{(m-2)r^2} + \cdots + \frac{1}{r^{m-1}}\right]$$

for m odd, (43)

$$= -\frac{1}{2r^m} \ln(1-r^2) - \left[\frac{1}{m} + \frac{1}{(m-2)r^2} + \cdots + \frac{1}{2r^{m-2}}\right]$$

for m even.

For an autoregressive process of order $p = 1$, the correction term [^] in Eq. 34 reduces to a constant times $(X_{k-m} - X_{k+m})$.

From the previous discussion it is seen that Minimum Variance Estimation of Y_k requires (except perhaps in the asymptotic case of very large m) detailed knowledge of the spectral density. Furthermore, a Minimum Variance Estimator of Y_k for one spectral density is not, in general, a Minimum Variance Estimator for another. In general, detailed knowledge of spectral densities is not available. Furthermore, for practical reasons, it is somewhat undesirable to use a different estimator for each spectral density. What is desired then are estimators that do well for a set of spectral densities, general purpose estimators so to speak. Such estimators are derived below. If more detailed knowledge of spectral densities is available it may be possible to modify these estimators so that they are more nearly optimal as previously discussed.

Flat and Narrow Band "In Phase" and "In Quadrature" Filters

Another criterion for choosing a finite moving average process $\bar{Y}_k$ which is a good approximation to Y_k is to determine the constants a_s, $s = -m, \cdots, 0, \cdots, m$ so that the matrix $\bar{S}(\omega)$ given by Eq. 15 is a good approximation to $S(\omega)$ given by Eq. 13. This method of approximation is justified since both the Y_k and the $\bar{Y}_k$ processes are linearly dependent on the X_k process. (This linear dependence or coherence implies that $\det S(\omega) \equiv 0$ and $\det \bar{S}(\omega) \equiv 0$. The identical vanishing of these determinants is easily verified from Eqs. 13 and 15.) From Eq. 15 it is evident that $\bar{S}(\omega)$ will approximate $S(\omega)$ if $f(\omega)$ given by Eq. 16 is such that $f(\omega) \approx 1$ in the frequency range ω where $s(\omega) \neq 0$. In the frequency range ω where $s(\omega) = 0$, $f(\omega)$ is arbitrary; however, it is desirable to take $f(\omega) \approx 0$ in order to filter out as much extraneous error noise as possible. Extraneous error noise is introduced, for example, in measuring or reading the X_k. An explicit expression for $f(\omega)$ having the properties just described is derived below. The derivation makes use of a filter formula obtained by Tukey.

Tukey has derived the function (filter)

$$T_m(\omega) \equiv \frac{1}{m} + \frac{2}{m}\sum_{j=1}^{m-1}\left(0.54 + 0.46\cos j\frac{\pi}{m}\right)\cos j\omega + \frac{1}{m}(0.54 + 0.46\cos\pi)\cos m\omega. \quad (44)$$

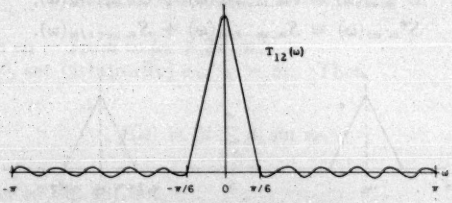

FIG. 1. Sketch of Tukey filter $T_{12}(\omega)$.

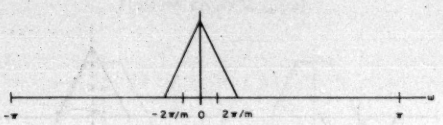

FIG. 2. Schematic sketch of Tukey filter $T_m(\omega)$.

A (rough) sketch of the Tukey filter $T_m(\omega)$ for $m = 12$ is shown in Fig. 1. The important thing to note is that $T_m(\omega)$ is a good approximation of a triangular band pass filter of width $4\pi/m$ centered at $\omega = 0$. Schematically, $T_m(\omega)$ is represented by Fig. 2.

Consider now the following two filters $C_{m,\omega_0}(\omega)$ and $S_{m,\omega_0}(\omega)$ defined by

$$\begin{aligned} C_{m,\omega_0}(\omega) &\equiv T_m(\omega - \omega_0) + T_m(\omega + \omega_0), \\ S_{m,\omega_0}(\omega) &\equiv T_m(\omega - \omega_0) - T_m(\omega + \omega_0). \end{aligned} \quad (45)$$

From Eqs. 44 and 45

$$\begin{aligned} C_{m,\omega_0}(\omega) &= \frac{2}{m} + \frac{4}{m}\sum_{j=1}^{m-1}\left(0.54 + 0.46\cos j\frac{\pi}{m}\right)\cos j\omega_0\cos j\omega \\ &\quad + \frac{2}{m}(0.54 + 0.46\cos\pi)\cos m\omega_0\cos m\omega, \\ S_{m,\omega_0}(\omega) &= \frac{4}{m}\sum_{j=1}^{m-1}\left(0.54 + 0.46\cos j\frac{\pi}{m}\right)\sin j\omega_0\sin j\omega \\ &\quad + \frac{2}{m}(0.54 + 0.46\cos\pi)\sin m\omega_0\sin m\omega. \end{aligned} \quad (46)$$

Schematic sketches of $C_{m,\omega_0}(\omega)$ and $S_{m,\omega_0}(\omega)$ for $\omega_0 \geq 2\frac{\pi}{m}$ are shown in Figs. 3 and 4.

Finally, consider the filters $C^*_{m,\omega_0}(\omega)$ and $S^*_{m,\omega_0}(\omega)$ defined by

$$\begin{aligned} C^*_{m,\omega_0}(\omega) &\equiv C_{m,\omega_0-\pi/m}(\omega) + C_{m,\omega_0+\pi/m}(\omega), \\ S^*_{m,\omega_0}(\omega) &\equiv S_{m,\omega_0-\pi/m}(\omega) + S_{m,\omega_0+\pi/m}(\omega). \end{aligned} \tag{47}$$

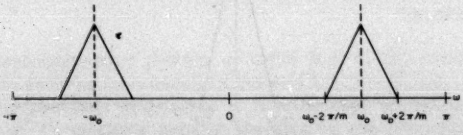

FIG. 3. Schematic sketch of filter $C_{m,\omega_0}(\omega)$.

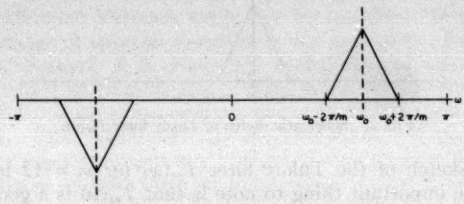

FIG. 4. Schematic sketch of filter $S_{m,\omega_0}(\omega)$.

From Eqs. 47 and 46

$$\begin{aligned} C^*_{m,\omega_0}(\omega) = \frac{4}{m} + \frac{8}{m}\sum_{j=1}^{m-1}\left(0.54+0.46\cos j\frac{\pi}{m}\right)\cos j\frac{\pi}{m}\cos j\omega_0\cos j\omega \\ + \frac{4}{m}(0.54+0.46\cos\pi)\cos\pi\cos m\omega_0\cos m\omega, \\ S^*_{m,\omega_0}(\omega) = \frac{8}{m}\sum_{j=1}^{m-1}\left(0.54+0.46\cos j\frac{\pi}{m}\right)\cos j\frac{\pi}{m}\sin j\omega_0\sin j\omega \\ + \frac{4}{m}(0.54+0.46\cos\pi)\cos\pi\sin m\omega_0\sin m\omega. \end{aligned} \tag{48}$$

Schematic sketches of $C^*_{m,\omega_0}(\omega)$ and $S^*_{m,\omega_0}(\omega)$ for m and ω_0 such that overlapping does not occur are shown in Figs. 5 and 6.

In summary, then, $C^*_{m,\omega_0}(\omega)$ and $S^*_{m,\omega_0}(\omega)$ are centered at ω_0 and essentially flat from $\omega_0 - \pi/m$ to $\omega_0 + \pi/m$ and essentially zero outside

the interval $\omega_0 - 3\pi/m$ to $\omega_0 + 3\pi/m$. Similar reasoning can be applied to obtain C and S filters that are flat over a wider band. For example,

$$\begin{aligned} C &= C_{m,\omega_0-2\pi/m} + C_{m,\omega_0} + C_{m,\omega_0+2\pi/m}, \\ S &= S_{m,\omega_0-2\pi/m} + S_{m,\omega_0} + S_{m,\omega_0+2\pi/m} \end{aligned} \tag{49}$$

are flat from $\omega_0 - 2\pi/m$ to $\omega_0 + 2\pi/m$.

In Eq. 16, set (arbitrarily) $a_{-s} = -a_s$. Then

$$f(\omega) = 2i \sum_{s=1}^{m} a_s \sin s\omega. \tag{50}$$

Finally (refer to Eq. 48), set

$$f(\omega) = iK_s S^*_{m,\omega_0}(\omega). \tag{51}$$

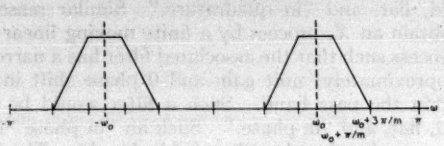

FIG. 5. Schematic sketch of filter $C^*_{m,\omega_0}(\omega)$.

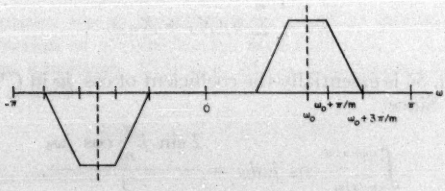

FIG. 6. Schematic sketch of filter $S^*_{m,\omega_0}(\omega)$.

From the properties of $S^*_{m,\omega_0}(\omega)$ it is clear that if the constant K_s is chosen appropriately $f(\omega) \approx i$ in the frequency range $(\omega_0 - \pi/m \leq \omega \leq \omega_0 + \pi/m)$. Furthermore, $f(\omega) \approx 0$ outside the range $(\omega_0 - 3\pi/m \leq \omega \leq \omega_0 + 3\pi/m)$. Since

$$\int_{\omega_0-\pi/m}^{\omega_0+\pi/m} \sin j\omega d\omega = \frac{2 \sin j\pi/m \sin j\omega_0}{j} \tag{52}$$

the constant K_s in Eq. 51 is given by

$$K_s = \left[\frac{1}{2\frac{\pi}{m}}\int_{\omega_0-\pi/m}^{\omega_0+\pi/m} S^*_{m,\omega_0}(\omega)d\omega\right]^{-1}$$

$$= \left[\frac{4}{\pi}\sum_{j=1}^{m-1}\frac{\left(0.54 + 0.46\cos j\frac{\pi}{m}\right)\sin 2j\frac{\pi}{m}\sin^2 j\omega_0}{j}\right]^{-1}. \quad (53)$$

The Y_k processes determined above can be thought of as follows: Each Y_k process is defined as a finite moving linear combination on the X_k process. A finite moving linear combination is a time invariant linear operator. To each time invariant linear operator there corresponds a frequency response function (filter). The frequency response functions (filters) determining the Y_k processes have a narrow pass band, and have (approximately) unit gain and $\pi/2$ phase shift in a frequency interval within the pass band. The filters can thus be described as narrow band, flat, and "in quadrature." Similar reasoning can be applied to obtain an $\tilde{X}_k$ process by a finite moving linear combination on the X_k process such that the associated filter has a narrow pass band and has (approximately) unit gain and 0 phase shift in a frequency interval within the pass band. Such a filter would be described as narrow band, flat, and "in phase." Such an "in phase" filter is given (apart from normalization) by $C^*_{m,\omega_0}(\omega)$ in Eq. 48. The finite moving average corresponding to such a filter is of the form

$$\tilde{X}_0 = \sum_{j=0}^{m} b_j(X_j + X_{-j}). \quad (54)$$

The b_j in Eq. 54 is essentially the coefficient of $\cos j\omega$ in $C^*_{m,\omega_0}(\omega)$ given by Eq. 48. Since

$$\int_{\omega_0-\pi/m}^{\omega_0+\pi/m}\cos j\omega d\omega = \frac{2\sin j\frac{\pi}{m}\cos j\omega_0}{j}, \quad (55)$$

the constant K_c required to normalize $C^*_{m,\omega_0}(\omega)$ is

$$K_c = \left[\frac{1}{2\frac{\pi}{m}}\int_{\omega_0-\pi/m}^{\omega_0+\pi/m} C^*_{m,\omega_0}(\omega)d\omega\right]^{-1}$$

$$= \left[\frac{4}{m}+\frac{8}{\pi}\sum_{j=1}^{m-1}\frac{\left(0.54+0.46\cos j\frac{\pi}{m}\right)\sin j\frac{\pi}{m}\cos j\frac{\pi}{m}\cos^2 j\omega_0}{j}\right]^{-1}. \quad (56)$$

The method of obtaining "in quadrature" filters explained above will not work for filters centered near zero frequency. The reason for

this is that the "non-overlapping" assumption no longer applies. The determination of approximate "in quadrature" filters centered near zero frequency therefore requires special study. That zero frequency should be a special case is to be expected. The "in quadrature" filter centered at zero is required to equal $+1$ to the right of zero and -1 to the left. There is, thus, a discontinuity at zero which is unavoidable. The finite sine polynomial approximation to such a function is expected to exhibit some sort of "Gibbs" phenomenon, that is, overshoot $+1$ to the right of zero and undershoot -1 to the left. The determination of good "in quadrature" filters centered near zero frequency seems difficult.

In summary, the following procedure (digital amplitude and phase meter) is suggested to determine amplitude and phase. From knowledge of the bandwidth of the spectral density determine, as explained above, suitable finite moving linear combinations to compute $\hat{X}_k$ and $\hat{Y}_k$. Determine $\hat{R}_k$ and $\hat{\phi}_k$ from $\hat{X}_k + i\hat{Y}_k = \hat{R}_k e^{i\hat{\phi}_k}$. If little error (noise) is present in X_k omit the computation of $\hat{X}_k$, that is, take $\hat{X}_k = X_k$.

Remarks on the Definition of Amplitude and Phase

Consider the (continuous parameter) process

$$X(t) = \int_0^\infty \cos \omega t \, dU(\omega) + \sin \omega t \, dV(\omega). \tag{57}$$

(In this discussion, the spectral density of the $X(t)$ process is permitted to be a δ function or a combination of δ functions.) A definition of instantaneous amplitude $R(t)$ and phase $\phi(t)$ having the following properties is desired:

(1) $$R(t)e^{i\phi(t)} = X(t) + iY(t),$$

where $Y(t)$ is obtained from $X(t)$ by a (fixed) linear time invariant operator. When

(2) $$X(t) = \cos \omega t, \qquad Y(t) = \sin \omega t,$$

when

$$X(t) = \sin \omega t, \qquad Y(t) = -\cos \omega t.$$

Condition (2) is imposed so that $[X(t), Y(t)]$ reduce to uniform, counterclockwise, circular motion when $X(t)$ is a pure sinusoid. Conditions (1) and (2) imply that

$$Y(t) = \int_0^\infty -\cos \omega t \, dV(\omega) + \sin \omega t \, dU(\omega). \tag{58}$$

The preceding remarks are given to justify the somewhat arbitrary appearing definition of amplitude and phase introduced earlier.

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GRAPHS WITH TWO KINDS OF ELEMENTS*

BY

S. L. HAKIMI[1]

ABSTRACT

Some of the fundamental properties of the graphs with two kinds of elements, red and black, are studied. An interesting property of a discrete function representing the number of trees with n red element as n varies over the possible range is discussed. Procedures are given by means of which one can find trees or 2-trees with maximum (or minimum) number of red elements. These results are used to find the number of poles and zeros of any network function of an RC network. The procedure is further modified to enable one to find the number of poles and zeros of network functions of an RLC network.

I. INTRODUCTION

In the recent years, the linear graph theory, developed mainly by Koenig (1),[2] Whitney (2, 3) and Veblen (4), has been applied to a variety of problems in network theory (5, 6, 7, 8). Since electrical networks are essentially graphs with different kinds of elements, it seems natural to study the properties of graphs with two kinds of elements and attempt, if possible, to generalize some of these results to the case of graphs with three or more kinds of elements.

We will concentrate on graphs with two kinds of elements, say red and black. After having obtained some of the basic properties of these graphs, they are applied to RC networks. A procedure is described by means of which one can find trees (or 2-trees) with maximum or minimum number of red elements. This result is used to find the number of poles and zeros of a driving-point or a transfer function of an RC network, without analyzing the network. It is shown that if one plots the number of trees as a function of the number of red elements in these trees (which is a set of discrete points) there are no local minima.

Some of the results presented here have been presented elsewhere in different forms (9, 10). These results are restated here, without proof, for the sake of completeness.

II. BASIC THEOREMS

A subgraph g of a graph G may be represented by the product of its elements. The ring sum of g_1 and g_2 represented by $g_1 \oplus g_2 = e_{k_1}e_{k_2} \cdots e_{k_r} = g_3$, corresponding to a subgraph which contains all elements in g_1 and g_2 except those which are in both. The union of g_1 and

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

g_2 is denoted by $g_1 \cdot g_2 = e_{q_1} e_{q_2} \cdots e_{q_l} = g_3$, corresponds to a subgraph that contains all of the elements of subgraphs g_1 and g_2. The subgraphs G_b and G_r correspond to the subgraphs containing all of the black and all of the red elements of G, respectively.

Theorem 1: The red elements of a graph G form a separable subgraph if and only if the number of red elements in every tree is the same.

Proof: If graph G contains separable graphs G_1, G_2, then any tree t_i of G may be written as $t_{i1} \cdot t_{i2}$ where t_{ik} is a tree of the subgraph G_k $(k = 1, 2)$. Therefore, if the red elements form a separable subgraph of G, then the number of red elements in every tree will be the same. Suppose that the number of red elements in every tree is the same. We like to show that the red elements form a separable subgraph. Assume otherwise, that is the red elements do not form a separable subgraph. From the definition of separable graphs (see Appendix), there exists a circuit C_{br} that contains red and black elements. Let C_{br} be a fundamental circuit of tree t_i (see Appendix), then removing any one of the elements of C_{br} from the subgraph $C_{br}t_i$ results in a tree of the graph G. Depending on whether one removes a black element or a red element from the subgraph $C_{br}t_i$, one obtains trees with different numbers of red elements; hence, a contradiction, which means that the red elements indeed form a separable subgraph.

Theorem 2: There exist no cut sets consisting of only red elements if and only if there exists a tree consisting of only black elements.

Proof: Every cut set contains at least an element of every tree (5); therefore, if there exists a tree consisting of only black elements, there is no cut set consisting of only red elements. On the other hand, if there exists a cut set consisting of only red elements, then removing all of these elements of this set from the graph reduces the rank of the graph by one which in turn means that there is no tree consisting of black elements only.

Theorem 3: There exist no circuits containing only red elements if and only if there exists a chord set which contains only black elements.

Proof: If there exists a chord set consisting of only black elements, then every circuit must contain black elements, for every circuit contains at least an element of this chord set. If there exist no circuits containing only red elements, removal of all of the black elements from the graph leaves a subgraph $G \oplus G_b$ that contains no circuits. Therefore the subgraph $G \oplus G_b$ is a subset of a tree. The subgraph G_b being the complement of $G \oplus G_b$ contains a chord set. Hence the theorem.

The proofs of the following theorems (stated differently) are given by Hakimi and Mayeda (9).

Theorem 4: If there exists a tree t_i with m red elements and a tree t_j with n red elements ($m > n$), then there exists a tree with k red elements for all k satisfying $n < k < m$.

A similar theorem can be stated concerning the 2-trees of the set $T_{i,j}$ where each 2-tree has vertices i and j in two different parts. This is simply because the 2-trees in $T_{i,j}$ are the trees of the original graph when the vertices i and j are shorted (collapsed).

Theorem 5: Let the set of 2-trees $T_{ij,o}$ in graph G be all of the 2-trees of graph G which have vertices i and j in one connected part and the vertex O in the other. If there exists a 2-tree $t^m_{ij,o}$ with m red elements and a 2-tree $t^n_{ij,o}$ with n red elements ($m > n$), then there exists a 2-tree $t^k_{ij,o}$ with k red elements for all k satisfying $n < k < m$.

It must be noted that in the case of the set of 2-trees $T_{ij,ko}$ the result of Theorem 5 does not apply. To see this, let us examine the graph of Fig. 1. The 2-trees in $T_{ij,ko}$ of the graph of Fig. 1 are ($a\ b\ c\ d$) and

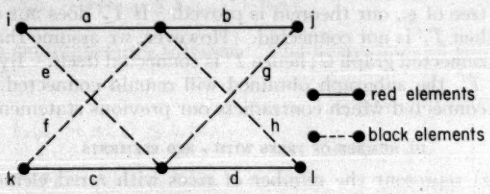

FIG. 1. An example of a graph with two kinds of elements.

($e\ f\ g\ h$), one 2-tree has four red elements and one 2-tree has none.

Let $\{e_{ri}\}$ be the set of elements of g_r, where g_r is a subgraph obtained from G by shorting[3] all black elements of G. Assume r_g is the rank of subgraph g_r.

Theorem 6: If T_{ib} is a tree of G_b and t_{ir} is a tree of g_r, then $T_i = T_{ib} \cdot t_{ir}$ is a tree of G.

Proof: We will show that T_i is a maximal circuit-less subgraph which is a tree. To do this, first suppose T_i contains a circuit C. C cannot contain only black elements for the black elements T_i form a tree of G_b. Assume that circuit C contains black and red elements. Shorting all of the black elements in T_i, we obtain a subgraph that (1) contains a circuit, or (2) does not contain all of the red elements in t_{ir}.[4] In either

[3] By shorting an element e_o of G, we mean removing e_o from G and collapsing together the two vertices to which e_o is connected.

[4] If the vertices of an element are shorted together, the element is removed from the graph, that is, no self-loop elements are allowed.

case this implies that the red elements in T_i cannot correspond to a tree of g_r. Therefore, T_i contains no circuits. Now we must show that it is not possible to add any elements to T_i without forming a circuit. Since T_i contains a tree of G_b, addition of any black elements to T_i would close a circuit. Suppose we can add a red element e_r to T_i without forming a circuit. Then shorting all of the black elements in $T_i e_r$, we obtain a graph which must be a subgraph of g_r and must not contain any circuits, but has more elements than a tree of g_r which is not possible. Hence the theorem.

Theorem 7: Every tree of G contains r_g elements of $\{e_{ri}\}$ which together form a tree of g_r.

Proof: Without the loss of generality, we shall assume that the graph is connected, for the same reasoning would hold for each maximally connected part of G (5). Let T' be a tree of G. We short all of the black elements in G and short all of the corresponding vertices in T'. We obtain a new subgraph T_r'. Subgraph T_r' is contained in g_r. If T_r' contains a tree of g_r, our theorem is proved. If T_r' does not contain a tree of g_r, then T_r' is not connected. However, we assume that T' was a tree of a connected graph G; hence T' is connected itself. By shorting vertices of T', the subgraph obtained will remain connected. Therefore, T_r' is connected which contradicts our previous statement.

III. NUMBER OF TREES WITH r RED ELEMENTS

Let $N(r)$ represent the number of trees with r red elements in a graph G. We would like to show that there exists no r such that $N(r) \leq N(r-1)$ and $N(r) \leq N(r+1)$. To prove this, we will make use of the following lemma:

Lemma 1: If polynomial

$$p_n(s) = a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0 \tag{1}$$

has only negative real zeros, then

$$\begin{cases} a_i \leq a_{i-1} \\ \qquad\qquad 0 < i < n \\ a_i \leq a_{i+1} \end{cases} \tag{2}$$

cannot be simultaneously satisfied.

Proof: We will prove this by induction. The lowest order polynomial which must be examined is

$$p_2 = a_2 s^2 + a_1 s + a_0. \tag{3}$$

Since the polynomial of Eq. 3 has only negative real zeros, a_0, a_1, and a_2 are positive and $a_1^2 - 4a_0a_2 \geq 0$. Let us assume that $a_1 \leq a_2$ which implies that $a_1 - 4a_0 \geq 0$ or $a_1 > a_0$. Hence our assertion is valid for $n = 2$. To complete the induction, let us assume the lemma is valid for polynomials of order up to $n - 1$. We must show that it is also valid for polynomial of order n. Since all zeros of polynomial p_n are assumed to be on the negative real axis, we may write

$$p_n = (b_1 s + b_0)p_{n-1} \tag{4}$$

or

$$p_n = b_1a_{n-1}s^n + (b_0a_{n-1} + b_1a_{n-2})s^{n-1} + \cdots + (b_0a_j + b_1a_{j-1})s^j + \cdots + a_0b_0. \tag{5}$$

We must now show that

$$\begin{cases} b_0a_j + b_1a_{j-1} \leq b_0a_{j-1} + b_1a_{j-2} \\ b_0a_j + b_1a_{j-1} \leq b_0a_{j+1} + b_1a_j \end{cases} \qquad 0 < j \leq n - 1\dagger \tag{6}$$

cannot be simultaneously satisfied. The inequalities of Eq. 6 may be written as

$$\begin{aligned} b_0(a_j - a_{j-1}) &\leq b_1(a_{j-2} - a_{j-1}) \\ b_0(a_j - a_{j+1}) &\leq b_1(a_j - a_{j-1}) \end{aligned} \qquad 0 < j \leq n - 1. \tag{7}$$

We will consider two different cases:

(1) $a_j \leq a_{j-1}$ which implies that $a_j > a_{j+1}$ which in turn means that the second inequality in Eq. 7 is not satisfied.

(2) $a_j \geq a_{j-1}$ which implies that $a_{j-1} > a_{j-2}$ which means that the first inequality in Eq. 7 is not satisfied. This ends the proof of the lemma.

Theorem 8: If $N(r)$ is the number of trees in graph G with r red elements, then there exists no i such that $N(i) \leq N(i+1)$ and $N(i) \leq N(i-1)$.††

Proof: Let all red elements in graph G be replaced by 1-farad capacitors and all black elements be replaced by 1-ohm resistors. The determinant of the nodal basis admittance matrix can be written as (6)

$$\Delta(s) = V(s) = \sum_{i=1}^{N} y_{i_1}y_{i_2} \cdots y_{i_{v-1}} = a_ns^n + \cdots a_is^i \cdots + a_0 \tag{8}$$

† $a_k = 0$ for $k < 0$ and $k > n - 1$.

†† At least one of the numbers $N(i)$, $N(i - 1)$, or $N(i + 1)$ must be non-zero.

where $y_{i_1}y_{i_2} \cdots y_{i_{r-1}}$ $(1 \leq i \leq N)$ is the product of the admittances of tree t_i and N is the number of trees in the graph. The tree admittance product

$$y_{k_1}y_{k_2} \cdots y_{k_{r-1}} = s^j \tag{9}$$

where j is the number of capacitors in this tree. Therefore, the coefficient a_i of the polynomial $\Delta(s)$ is equal to the number of trees with i capacitors. Hence, we may write polynomial $V(s)$ as follows:

$$V(s) = \Delta(s) = N(n)s^n + N(n-1)s^{n-1} + \cdots N(0). \tag{10}$$

From our knowledge of RC networks we know that zeros of $\Delta(s)$ are on the non-positive real axis. Therefore, the result of Lemma 1 proves the theorem.

Corollary 1: If $N(r)$ is the number of 2-trees in $T_{i,j}$ of a graph G with r red elements, then there exists no i such that $N(i) \leq N(i+1)$ and $N(i) \leq N(i-1)$.

Proof of this corollary is entirely the same as the previous theorem, for all 2-trees in $T_{i,j}$ are trees of G when vertices i and j are shorted.

A similar theorem concerning the 2-trees in $T_{ij,0}$ of a graph G seems to be true but will require a completely different type of proof.

V.2
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IV. TREES AND 2-TREES WITH MAXIMUM NUMBER OF RED ELEMENTS

We will be primarily concerned with the problem of finding trees and 2-trees with maximum (or minimum) number of red elements n_r. We would also like to find formulas by which we can determine n_r without finding these trees (or 2-trees). This problem is relatively simple for the case of trees and has been previously attacked by Reza (11). The treatment here is more complete, for the case of 2-trees is also considered.

Theorem 9: The number of red elements in any tree of G is at most equal to R_r where R_r is the rank of the red subgraph G_r.

Proof: Consider a tree t_r of the red subgraph G_r. Tree t_r has R_r red elements. Since t_r is a subset of some tree of G, there exists a tree that contains R_r red elements. On the other hand, since any $R_r + 1$ combination of red elements contains a circuit, there exists no tree with more than R_r red elements. To find a tree with maximum number of red elements, one can start with a tree of G_r and add to t_r as many elements of G_b as possible without forming a circuit.

Corollary 1: The number of red elements in all 2-trees in the set $T_{i,j}$ of graph G is at most equal to $R_{r_{i,j}}$ where $R_{r_{i,j}}$ is the rank of the red subgraph when vertices i and j are shorted.

Proof: The 2-trees in $T_{i,j}$ are the trees of G when vertices i and j are shorted. Therefore, this result is a simple consequence of the previous theorem.

The next step in the development would be to find a 2-tree in $T_{ij,kl}$ with maximum number of red elements. A 2-tree in $T_{ij,kl}$ of a connected graph G is a 2-tree which has vertices i and j in one connected part and vertices k and l in the other.

Let $\{s_i\}$ be the set of those cut sets of the graph G such that for every cut set s_i in $\{s_i\}$, $G \oplus s_i$ is a subgraph with vertices i and j in one part and vertices k and l in the other. Let m be the number of separable parts of the red subgraph G_r (see Appendix). Assume that s_i in $\{s_i\}$ intersects p_i separable subgraphs of G_r. Let $p = \min [p_1, p_2, \cdots, p_n]$ where n is the number of cut sets in $\{s_i\}$. Let a cut set in $\{s_i\}$ which intersects p separable subgraphs of G_r be called a "least cut set." If s_p is a cut set such that $G \oplus s_p$ is a subgraph in which vertices i and j are in two different parts, then we say that the cut set s_p separates vertices i and j.

Lemma 2: Every tree of the subgraph $G \oplus s_i$ (s_i in $\{s_i\}$) is a 2-tree in $T_{ij,kl}$ of the graph G, and also for every 2-tree t_i in $T_{ij,kl}$ of G there exists one cut set s_i in $\{s_i\}$ such that t_i is a tree of $G \oplus s_i$.

Proof: The fact that every tree of $G \oplus s_i$ is a 2-tree in $T_{ij,kl}$ of graph G is obvious. We like to prove that every 2-tree in $T_{ij,kl}$ is a tree of $G \oplus s_i$ for some s_i in $\{s_i\}$. Consider a 2-tree t_j in $T_{ij,kl}$. Let those elements of G that connect the two isolated parts of t_j be $s_j' = e_{j_1} e_{j_2} \cdots e_{j_k}$. It is clear that t_j is a tree of the subgraph $G \oplus s_j'$. To see that s_j' is a cut set in $\{s_i\}$, one must remember that the elements of s_j' are the only elements in G that connected the two isolated parts of t_j, and each of the isolated parts is connected.

Theorem 10: The maximum number of red elements in the 2-trees in $T_{ij,kl}$ is equal to $R_r - p$.

Proof: Let R_{r_i} be the rank of the red subgraph of $G \oplus s_i$. It is easy to see that $R_{r_i} = R_r - p_i$. From Theorem 9, the maximum number of red elements in a tree of $G \oplus s_i$ is equal to R_{r_i}. If s_k is a least cut set, then R_{r_k} is a maximum and is equal to $R_r - p$. Therefore, a tree of $G \oplus s_k$ with $R_r - p$ red elements exists and is a 2-tree (in $T_{ij,kl}$) of G. The problem of finding a 2-tree of a graph G with maximum number of red elements is still a formidable task. However, the result of the Theorem 10 can be used, in some cases, to find a 2-tree with maximum number of red elements with great ease. For example, consider the graph of Fig. 2. We like to find the number of red elements in a 2-tree in $T_{ij,kl}$ with maximum number of red elements. By inspection one can see that the elements intersected by the line s_k form a least cut set.

Since it only intersects one red element and the rank of the red subgraph is 7, the maximum number of red elements in 2-trees of G is 6. One of the main difficulties of the suggested process for finding a 2-tree in $T_{ij,kl}$ of G with maximum number of red elements is the problem of finding a least cut set. In many cases this may be done by inspection, but in general, one must find all of the cut sets in $\{s_i\}$ and examine each cut set separately to see which one is a least cut set. The following theorems suggest an algebraic way of producing the cut sets in $\{s_i\}$.

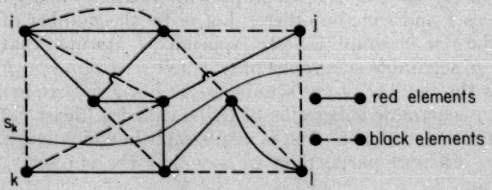

FIG. 2. A least cut set.

Theorem 11: If s_{i_1}, s_{i_2}, and s_{i_3} are three cut sets in $\{s_i\}$ and if the subgraph $s_{i_1} \oplus s_{i_2} \oplus s_{i_3} \oplus G$ contains a path between vertices i and j and also a path between vertices k and l, then $s_i' = s_{i_1} \oplus s_{i_2} \oplus s_{i_3}$ is either a cut set in $\{s_i\}$ or s_i' is a disjoint union of cut sets one of which is a cut set in $\{s_i\}$.

Proof: Mayeda (12) has shown that the ring sum of three cut sets separating vertices i and j is either a cut set separating the same pair of vertices or is a disjoint union of cut sets one of which separates i and j. Here, we like to show a similar result concerning the cut sets in $\{s_i\}$. From the definition of the set $\{s_i\}$, the subgraph $G \oplus s_k$, for every cut set s_k in $\{s_i\}$, contains a path between vertices i and j and also a path between vertices k and l. Let graph G' be constructed from G by shorting vertices i and j and also vertices k and l. Then, for every s_k in $\{s_i\}$ the subgraph $G' \oplus s_k$ contains a circuit going through the vertex $k = l$ and a circuit going through vertex $i = j$. In the graph G each of the cut sets in $\{s_i\}$ is a cut set separating vertices i and k. Hence, by Mayeda's result the ring sum s_i' of any three cut sets in $\{s_i\}$ will be either a cut set separating vertices i and k or a disjoint union of cut sets, one of which separates vertices i and k. From the hypothesis, however, $G' \oplus s_i'$ contains a circuit going through the vertex i and a circuit going through the vertex k. Therefore, we can conclude that s_i' is either a cut set in $\{s_i\}$ or a disjoint union of cut sets one of which is in $\{s_i\}$. This technique may be used to generate cut sets in $\{s_i\}$.

Suppose we are to find the maximum number of red elements in any of the 2-trees in $T_{ij,kl}$ and $T_{il,jk}$.[8] Let $T_{k,l}^{i,j}$ be the set of all 2-trees in

[8] This number turns out to be of importance in finding the number of zeros of transmission of an RC two terminal-pair network.

$T_{ij,kl}$ and $T_{il,jk}$. We like to compute the maximum number of red elements that a 2-tree in $T^{i,j}_{k,l}$ can have. To do this we shall propose an entirely similar procedure as discussed in the previous case. Namely, we shall attempt to find the set of all cut sets $\{s_j\}$ such that for any cut set s_j in $\{s_j\}$ the subgraph $G \oplus s_j$ has no path between both vertices i and k and j and l. It must be noted that this requires that the subgraph $G \oplus s_j$ must either have a path between vertices i and j and also a path between vertices k and l, or it must have a path between vertices i and l and also a path between vertices j and k. As before, we must find a least cut set in $\{s_j\}$, then the maximum number of red elements in 2-trees of $T^{i,j}_{k,l}$ is $R_r - p$ where R_r and p refer to the same quantities as defined before.

In the light of our previous arguments, whatever is claimed in the last paragraph is self-explanatory. It turns out that it is simple to generate the set of all cut sets in $\{s_j\}$. The technique of generating all cut sets in $\{s_j\}$ is described in the following theorem:

Theorem 12: Let $\{s_p\}$ be the set of all cut sets separating vertices i and k and let $\{s_q\}$ be the set of all cut sets separating vertices j and l, then the intersection of these two sets (that is, those cut sets that appear in both $\{s_p\}$ and $\{s_q\}$) is $\{s_j\}$.

Proof: From the definition of $\{s_j\}$, it is clear that a cut set in $\{s_j\}$ is a cut set in $\{s_q\}$ and in $\{s_p\}$. Now, we like to show that if a cut set s_r is in both $\{s_p\}$ and $\{s_q\}$, then s_r is in $\{s_j\}$. If s_r is in $\{s_p\}$ and $\{s_q\}$, then the subgraph $G \oplus s_r$ has no path between both vertices i and k and vertices j and l. This indeed proves that s_r is in $\{s_j\}$, which proves the theorem.

From this theorem, we can see that we can generate all of the cut sets in $\{s_j\}$ merely by generating all cut sets in $\{s_p\}$ and $\{s_q\}$ and then finding the common elements of $\{s_p\}$ and $\{s_q\}$. To generate all of the cut sets in, say $\{s_p\}$, we must first pick from the graph R independent cut sets[6] each of which separates vertices i and k. Then, the ring sum of any odd number of cut sets is either in $\{s_p\}$ or is a disjoint union of cut sets one of which is in $\{s_p\}$. By taking the ring sum of all possible combinations of odd number of cut sets, we find all of the cut sets in $\{s_p\}$ (12). If any such combination of odd number of cut sets produces a cut set s_0 which is a disjoint union of cut sets one of which is in $\{s_p\}$, then cut set s_0 may be eliminated by merely comparing it to some other cut sets in $\{s_p\}$ which are contained in s_0.

V. THE NUMBER OF POLES AND ZEROS OF NETWORK FUNCTIONS

For the RLC network of Fig. 3, the open-circuit impedance functions in terms of topological quantities (trees, 2-trees) may be written as (6)

[6] The number of independent cut sets in a graph under the ring sum operation is equal to the rank of that graph (5).

$$\left.\frac{V_1}{I_1}\right|_{I_2=0} Z_{11} = \frac{W_{i,k}}{V}$$

$$\left.\frac{V_2}{I_1}\right|_{I_2=0} Z_{12} = \frac{W_{ij,kl} - W_{il,jk}}{V} \tag{11}$$

where

$$V = \sum_{i=1}^{N} Y_{i_1} Y_{i_2} \cdots Y_{i_{v-1}} \tag{12}$$

and

$$W_{ab,cd} = \sum_{j=1}^{M} Y_{j_1} Y_{j_2} \cdots Y_{j_{v-2}}. \tag{13}$$

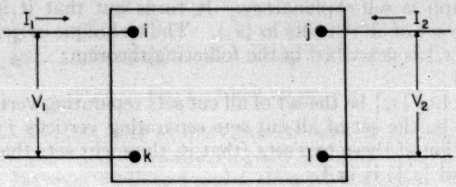

FIG. 3. Reference conventions for a two terminal-pair network.

The elements of the sum in the right-hand side of Eq. 12 ($Y_{i_1} Y_{i_2} \cdots Y_{i_{v-1}}$, $1 \leq i \leq N$) are the products of the admittances of the branches of trees in the network. The elements of the sum in the right-hand side of Eq. 13 ($Y_{j_1} Y_{j_2} \cdots Y_{j_{v-2}}$, $1 \leq j \leq M$) are the products of the admittances of the branches of 2-trees, each 2-tree having vertices a and b in one connected part, and vertices c and d in the other. The vertices a and b (c and d) may not be unique. The integers v, N, and M are the number of vertices, the number of trees, and the number of such 2-trees in the network, respectively. To find the number of poles of these functions, we will consider the polynomial

$$V(s) = \sum_{i=1}^{N} Y_{i_1} Y_{i_2} \cdots Y_{i_{v-1}} = a_n s^n + a_{n-1} s^{n-1} + \cdots + a_m s^m. \tag{14}$$

Let us assume that the network of Fig. 3 is an RC network. Then, we can see that n is the maximum number of capacitors in all trees of the network. Hence $n = R_e$ where R_e is the rank of the subnetwork N_e which consists of all capacitors of the network. Similarly the number of zeros of $W_{i,k}$ is equal to $R_{e_{i,k}}$, the rank of the subnetwork N_e when vertices i and k are shorted. However, these numbers are not exactly the same as the number of poles and zeros of Z_{11}, for there could

be cancellation of the common factors of the numerator and the denominator. All of these common factors are functions of the element values, except the zeros of $V(s)$ and $W_{i,k}(s)$ at the origin. Therefore, we like to know the multiplicity of the zeros of $V(s)$ and $W_{i,k}(s)$ at the origin. From Eq. 14 we can see that m is equal to the minimum number of capacitors in a tree of the network, which is equal to $R - R_r$ where R_r is the rank of the resistive subnetwork and R is the rank of the network. Similarly the multiplicity of the zeros of $W_{i,k}$ at the origin is equal to $R - R_{ri,k} - 1$ where $R_{ri,k}$ is the rank of the resistive subnetwork when vertices i and k are shorted. Since the min $[R - R_r, R - R_{ri,k} - 1] = R - R_{ri,k} - 1$, we can conclude that the number of poles of Z_{11} is equal to $R_e - (R - R_{ri,k} - 1)$ and the number of zeros of Z_{11} is equal to $R_{ei,k} - (R - R_{ri,k} - 1)$.

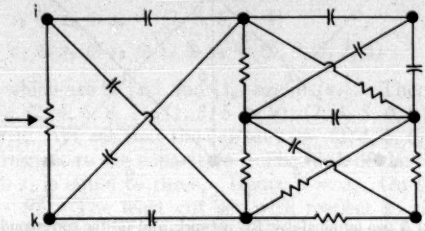

FIG. 4. An RC network.

Example 1: Consider the RC network of Fig. 4. By inspection, we can see that $R = 7$, $R_e = 7$, $R_{ei,k} = 6$, and $R_{ri,k} = 4$.

The number of poles of $Z_{11} = R_e - (R - R_{ri,k} - 1) = 5$.

The number of zeros of $Z_{11} = R_{ei,k} - (R - R_{ri,k} - 1) = 4$.

Our next task is to find the number of zeros of Z_{12} for an RC network. Consider the polynomial

$$W_{ij,kl} - W_{il,jk} = a_p s^p + a_{p-1} s^{p-1} + \cdots + a_q s^q. \qquad (15)$$

The number of zeros of the polynomial of Eq. 15 is equal to p. p is equal to the maximum number of capacitors that a 2-tree in $T^{i,j}_{k,l}$ can have. We can evaluate p by the process described in the previous section. On the other hand, to find q we must calculate the minimum number of capacitors in the 2-trees in $T^{i,j}_{k,l}$. This can be evaluated by finding the maximum number of resistors R^{ij}_{kl} in the 2-trees in $T^{i,j}_{k,l}$ and subtracting it from the number of elements in a 2-tree, R − 1.

Example 2: Find the number of zeros of Z_{12} of the network of Fig. 5. To find the number of zeros of Z_{12}, we first find the cut sets in $\{s_j\}$.

However, the set $\{s_j\}$ is the intersection of the two sets $\{s_p\}$ and $\{s_q\}$. Let us first find the cut sets in $\{s_p\}$,

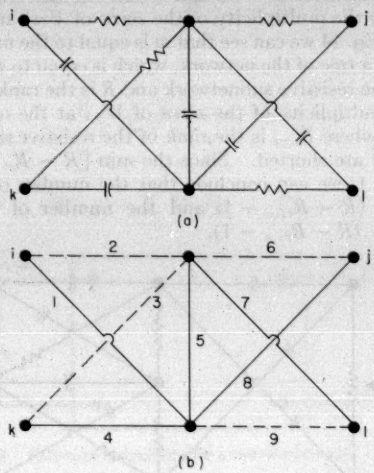

FIG. 5. (*a*) A two terminal-pair RC network, and (*b*) the corresponding graph.

Pick $s_1 = (1, 2)$, $s_2 = (3, 4)$, $s_3 = (1, 3, 5, 7, 6)$, $s_4 = (1, 3, 5, 8, 9)$, and $s_5 = (1, 3, 5, 8, 7)$ from the graph of Fig. 5*b* and proceed as follows

$$s_6 = s_1 \oplus s_2 \oplus s_3 = (2, 4, 5, 7, 6)$$
$$s_7 = s_1 \oplus s_2 \oplus s_4 = (2, 4, 5, 8, 9)$$
$$s_8 = s_1 \oplus s_2 \oplus s_5 = (2, 4, 5, 8, 7)$$
$$s_9 = s_1 \oplus s_3 \oplus s_4 = (1, 2, 7, 6, 8, 9)$$
$$s_{10} = s_1 \oplus s_3 \oplus s_5 = (1, 2, 6, 8) \quad \text{Union of cut sets}$$
$$s_{11} = s_1 \oplus s_4 \oplus s_5 = (1, 2, 7, 9)$$
$$s_{12} = s_2 \oplus s_3 \oplus s_4 = (3, 4, 7, 6, 8, 9)$$
$$s_{13} = s_2 \oplus s_3 \oplus s_5 = (3, 4, 8, 6) \quad \text{Union of cut sets}$$
$$s_{14} = s_2 \oplus s_4 \oplus s_5 = (3, 4, 7, 9)$$
$$s_{15} = s_3 \oplus s_4 \oplus s_5 = (1, 3, 5, 6, 9)$$
$$s_{16} = s_1 \oplus s_2 \oplus s_3 \oplus s_4 \oplus s_5 = (2, 4, 5, 6, 9)$$

To find the cut sets in $\{s_q\}$, start with the following independent cut sets obtained from the graph of Fig. 5*b*, and form the rest as follows

$\{s_q\}$: $s_1 = (6, 8)$, $s_2 = (7, 9)$, $s_3 = (7, 8, 5, 1, 4)$, $s_4 = (7, 8, 5, 1, 3)$, and $s_5 = (8, 7, 3, 2, 5)$

$$
\begin{aligned}
s_6 &= s_1 \oplus s_2 \oplus s_3 = (6, 9, 5, 1, 4)\\
s_7 &= s_1 \oplus s_2 \oplus s_4 = (6, 9, 5, 1, 3)\\
s_8 &= s_1 \oplus s_2 \oplus s_5 = (6, 9, 5, 3, 2)\\
s_9 &= s_1 \oplus s_3 \oplus s_4 = (6, 8, 3, 4)\\
s_{10} &= s_1 \oplus s_2 \oplus s_5 = (6, 8, 1, 4, 3, 2) \quad \text{Union of cut sets}\\
s_{11} &= s_1 \oplus s_4 \oplus s_5 = (6, 8, 1, 2)\\
s_{12} &= s_2 \oplus s_3 \oplus s_4 = (7, 9, 3, 4)\\
s_{13} &= s_2 \oplus s_3 \oplus s_5 = (7, 9, 1, 4, 2, 3) \quad \text{Union of cut sets}\\
s_{14} &= s_2 \oplus s_4 \oplus s_5 = (7, 9, 1, 2)\\
s_{15} &= s_3 \oplus s_4 \oplus s_5 = (7, 8, 5, 2, 4)\\
s_{16} &= s_1 \oplus s_2 \oplus s_3 \oplus s_4 \oplus s_5 = (6, 9, 5, 2, 4)
\end{aligned}
$$

The cut sets which are in $\{s_p\}$ and $\{s_q\}$ are in $\{s_j\}$. Therefore cut sets: (1, 3, 5, 8, 7), (2, 4, 5, 8, 7), (1, 3, 5, 6, 9), (2, 4, 5, 6, 9) are all of the cut sets in $\{s_j\}$. We see that the cut set $s_0 = (2, 4, 5, 6, 9)$ is the least cut set with respect to the capacitors. The rank of the capacitive subgraph of $G \oplus s_0$ is equal to three. Hence $p = 3$. On the other hand $q = R - 1 - R_M^{ij}$. The least cut set with respect to the resistors is $s_0' = (1, 3, 5, 8, 7)$ and the rank of resistive subgraph of $G \oplus s_0' = 3 = R_M^{ij}$. Therefore, $q = 1$. However since $V(s)$ has a simple zero at the origin, the zero of $W_{ij,kl} - W_{il,jk}$ at the origin cancels out. Therefore Z_{12} has only 2 zeros.

All other network functions of an RC network can be treated similarly. We have not considered the short-circuit functions, but their treatment is very similar with the exception that we must find the "3-trees"[7] with maximum and minimum number of capacitors (6).

We will concentrate our attention on the more general problem of finding the number of poles and zeros of network functions of RLC networks. As before, we will start with the number of zeros of $V(s)$

$$V(s) = a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0 + a_{-1} s^{-1} + \cdots a_{-m} s^{-m}.$$

Highest power of $V(s)$ is due to the tree-admittance products which contain a maximum number of capacitors and a minimum number of inductors. To find n, we start with a tree of capacitive subnetwork N_c which contains R_c capacitors. To this tree, we add as many inductors as it is absolutely necessary to obtain a tree of the complete network. Due to Theorems 6 and 7, this number of inductors is equal to rank of

[7] A 3-tree $t_{i,j;k,l}$ of G is a tree of the graph G when vertices i and j and vertices k and l are shorted.

the network when all of the resistors and the capacitors of the network are shorted. We can conclude that $n = R_e - R_{src}$, where R_{src} is the rank of the network when all of the capacitors and resistors are shorted. On the other hand, the lowest power $V(s)$ is due to the tree-admittance products of the network with a maximum number of inductors and minimum number of capacitors. We can easily see that $m = R_L - R_{srl}$, where R_L is the rank of the subnetwork consisting of all inductors and R_{srl} is the rank of the network when all resistors and inductors are shorted. Therefore, the number of zeros of $V(s)$ is equal to $R_L + R_e - (R_{srl} + R_{src})$ (11). Similarly, it can be shown that the number of zeros of $W_{i,k}$ is $R_{Li,k} + R_{ei,k} - (R_{srei,k} + R_{srli,k})$ where the subscript (i, k) signifies that ranks of subgraphs are evaluated when vertices i and k are shorted.

Our most complicated task is to find the number of zeros of transmission for a two terminal-pair RLC network, or the number of zeros of

$$W_{ij,kl} - W_{il,jk} = a_n s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0 + a_{-1}s^{-1} + \cdots + a_{-m}s^{-m} \quad (16)$$

where vertices i and k signify the input terminals and the vertices j and l signify the output terminals. The number of zeros of the function of Eq. 16 is equal to $m + n$. Hence we must evaluate m and n. The coefficient a_i in the function of Eq. 16 is due to 2-trees in T^{ij}_{kl} in which the number of capacitors n_{ei} minus the number of inductors n_{li} is equal to i; we would like to find the minimum and the maximum values of i. We will first calculate n which corresponds to a maximum value of i. To do this we remove as many inductors from the network as possible without either causing a vertex to be completely isolated or breaking all paths from i to j, from k to l, from i to l, and from j to k. More specifically, if the original network has a path p_{ij} from i to j and a path p_{kl} from k to l that had no common vertices, the new network must have the same property. The same statement also holds for the vertices i, l and j, k. To illustrate this further, let us consider the two terminal-pair RLC network of Fig. 6*a*. Figure 6*b* shows the network obtained after removing all inductors from the network of Fig. 6*a*. Note that three are paths from vertex i to j and also from vertex k to l in Fig. 6*b*. However, there is no path between vertices i and l that does not have any vertices in common with a path from k to j. By adding inductance e_1 to the network of Fig. 6*b*, we reconnect such a path. In Fig. 6*c*, $p_{il} = e_1e_2e_3e_4$, $p_{kj} = e_5e_6e_7e_8$ are two paths that have no common vertices. Inductance e_9 is placed back in the network of Fig. 6*c* to reconnect the isolated vertex of the network of Fig. 6*b*. Let the network thus constructed be denoted by N_L. Now we must find the least cut set with respect to capacitors in $\{s_j\}$ that contains a maximum number of inductors. Let s_0 be such a cut set. Then n is equal to $R_{e0} - n_1$

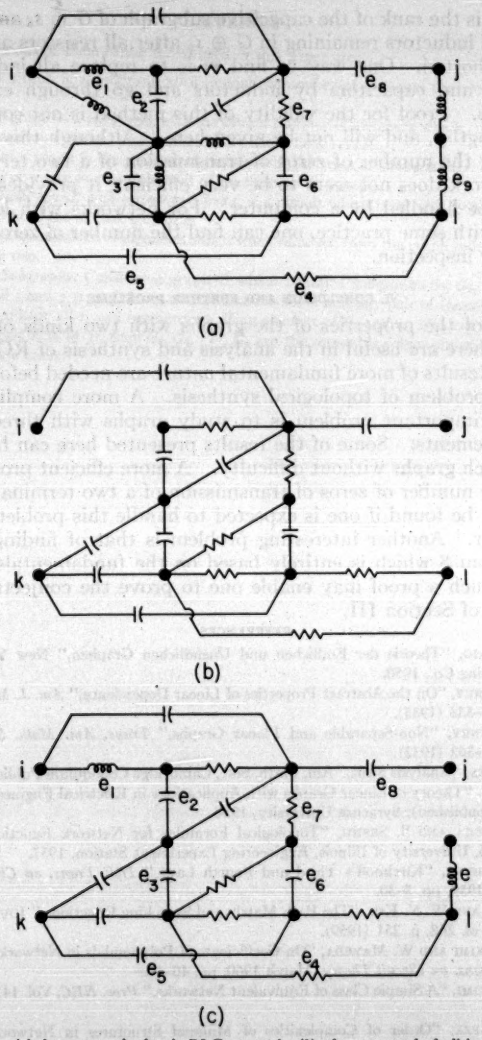

FIG. 6. (*a*) A two terminal-pair RLC network, (*b*) after removal of all inductors, and (*c*) after the necessary inductors are reinserted.

where R_{c0} is the rank of the capacitive subgraph of $G \oplus s_0$ and n_1 is the number of inductors remaining in $G \oplus s_0$ after all resistors and capacitors are shorted. One way to find m is to replace all inductors by capacitors and capacitors by inductors and go through exactly the same steps. Proof for the validity of this method is not complicated, though lengthy, and will not be given here. Although this procedure for finding the number of zeros of transmission of a two terminal-pair RLC network does not seem to be very efficient, it provides a scheme that can be handled by a computer. For networks with less than 8 vertices, with some practice, one can find the number of zeros of transmission by inspection.

VI. CONCLUSION AND FURTHER PROBLEMS

Many of the properties of the graphs with two kinds of elements described here are useful in the analysis and synthesis of RC networks (9, 10). Results of more fundamental nature are needed before one can solve the problem of topological synthesis. A more complicated and seemingly important problem is to study graphs with three or more kinds of elements. Some of the results presented here can be generalized for such graphs without difficulty. A more efficient procedure for finding the number of zeros of transmission of a two terminal-pair network must be found if one is expected to handle this problem without a computer. Another interesting problem is that of finding proof of the Theorem 8 which is entirely based on the fundamentals of graph theory. Such a proof may enable one to prove the conjecture stated at the end of Section III.

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APPENDIX

The definitions of some of the terms used in this paper are:

A *tree* of a graph is a subgraph with maximum number of elements that has no circuits (loops).

A *2-tree* of graph is a subgraph with maximum number of elements which consists of two isolated parts and no circuits, each isolated part could be a vertex.

The *rank* of a graph is the number of elements in the trees of that graph.

A *chord set* of a tree is a complement of that tree of the graph.

A *fundamental circuit with respect to a tree* t_i is a circuit which is formed by addition of an element of the chord set of that tree to t_i.

A *cut set* is a minimal set of elements which when removed from the graph reduces the rank of the graph by one.

Separable Subgraphs: Consider a graph G which contains subgraphs $G_1, G_2, \cdots, G_n$. If G_i and G_j for all i and j $(i \neq j)$ have no common elements and any pair of elements of G_i can be put in a circuit for all i, and furthermore, if an element of G_i and an element of G_j cannot be put in a circuit if $(i \neq j)$, then $G_1, G_2, \cdots, G_n$ are the separable subgraphs of G and graph G has n separable parts.

ON PARAMETRIC EXCITATION WITH CURRENT SATURABLE INDUCTANCES*

BY

NOAH S. PRYWES[1]

ABSTRACT

A parametric amplifier circuit is described. The nonlinearity involved is an abrupt one and a method of analysis of "relaxation oscillations" is preferred to techniques assuming quasi-linearity. This leads to a physical understanding of the cycle of oscillations as well as quantitative relationships which are helpful to the designer. The stability problem is also solved establishing the switching requirements.

1. INTRODUCTION

The circuit described in this paper has two modes of operation. In the "off" mode very small currents flow in the circuit. The "on" mode corresponds to large oscillations of currents and voltage at an odd multiple of the supply frequency. Switching from one mode to the other is possible through application of an electrical impulse to the circuit.

The power to the circuit is provided from an alternating supply source. The supply alternating current changes the parameters of a nonlinear inductance in the circuit. Specifically, it changes the flux-current characteristic of the inductance. Transfer of power to the load is effected then through this parametric excitation.

The nonlinearity of the current saturable inductance is abrupt so that analysis based on an assumption of quasi-linearity provides qualitative results at best (3).[2] The method of analysis used here is similar to that of a previously published paper on parametric excitation in a circuit having a nonlinear capacitance (1).

Experimental evidence indicates efficient transfer of power at 1, 3 and 5 multiples of supply frequencies of 60 and 400 cps. The usefulness of the circuit in this range is mainly in efficient frequency multiplication. At higher frequencies the hysteresis losses limited the experimental operation. If use is to be made of new materials, such as recently developed films, operation at higher frequencies approaching one kilo-

* A current saturable inductance is so named to signify that the nonlinearity in the magnetic characteristic is such that in the region of saturation a large change in magnetic flux is associated with a small change in the magnetic field. The name was first suggested to the author in 1953 by Prof. R. Rudenburg of Harvard University.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

megacycle will be feasible. In an expanded frequency range the circuit has promise as a bistable device in memory and logic applications (4).

The method of analysis consists of assuming that a large disturbance from the "off" mode is introduced. The operation following this disturbance is analyzed leading to the description of the "on" mode. In the discussion, a loss-less (zero load) circuit is considered first. The manner of power transfer is then outlined and a practical case of non-zero load is considered. This leads to the definition of conditions of balance of input and output powers. The stability, which is the other requirement of the operation, is discussed last.

2. CIRCUIT AND CHARACTERISTIC

The circuit by which the current saturable inductance is achieved is shown in Fig. 1. The bias circuit can be replaced by permanent magnets in the magnetic path of the two cores, providing the same

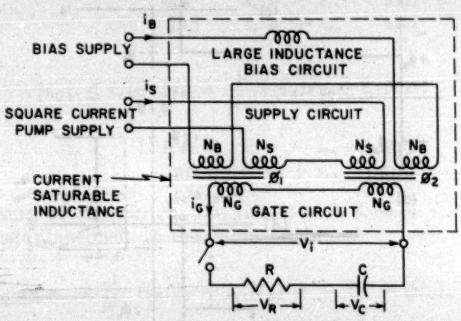


FIG. 1. Circuit for parametric oscillator at a frequency which is an odd integer multiple of the pump frequency.

field. The energy supply is in the form of a square wave current of i_{so} amplitude flowing in supply circuit windings. The supply circuit current (i_s) is shown in Fig. 2. The magnetic characteristic of each core

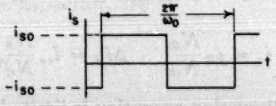


FIG. 2. Supply circuit current.

is simplified by approximating the unsaturated parts by vertical lines and the flux saturated parts by horizontal lines as shown in Fig. 3*a*. The construction of the current saturable inductance flux current char-

acteristic is shown in Fig. 3. Figure 3*b* gives the flux (ϕ) *vs.* the gate circuit current (i_G) characteristic of one core and Fig. 3*c* of the other core. Adding up the fluxes of the two cores, through series connection of the windings, the total flux (ϕ) *vs.* the gate circuit current (i_G) is obtained as shown in Fig. 3*d*. Current saturation is achieved along

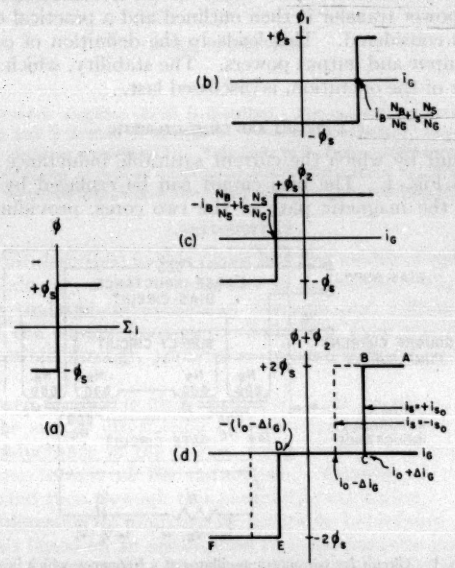


FIG. 3. Simplified characteristic of current saturable inductance.

the parts *BC* and *DE* of the characteristic. If operation is limited to the BCDE region of Fig. 3*d*, a current saturable characteristic is obtained, as opposed to the flux saturable characteristic of Fig. 3*a*. The characteristics at $i_s = +i_{so}$ and $i_s = -i_{so}$ are drawn in Fig. 3*d*, where[3]

$$i_o = i_B \frac{N_B}{N_G} \qquad \Delta i_G = i_{so} \frac{N_S}{N_G}. \tag{1}$$

In the following discussion operation is limited to part *BCDE* of the characteristic of Fig. 3*d*.

During the period through which i_s stays constant, that is, $i_s = i_{so}$ or $i_s = -i_{so}$, only the gate circuit need be considered. The current

[3] A list of symbols used is appended to this paper.

saturable inductance is then a nonlinear element with the flux-current characteristics of Fig. 3*d*.

3. SPECIAL CASE, $R = 0$

Let us consider the gate circuit of the circuit in Fig. 1. With the switch open the capacitor c is charged until the voltage across it is $V_c = V_{co}$. Let the switch in the gate circuit be closed at time $t = 0$ when $i_s = +i_{so}$. Prior to closing the switch, the flux $\phi = 0$. At the instant of closing the switch, current limited by the current saturable inductance will start flowing in the gate circuit discharging the capacitor. From the characteristic in Fig. 3*d*, the current i_G is limited as follows:

$$|i_G| \leq i_o + \Delta i_G = \frac{1}{N_G} |(i_B N_B + i_{so} N_S)|$$

$$\begin{array}{llll} \text{for} & i_s = +i_{so} & \text{and} & \phi > 0 \\ \text{and} & i_s = -i_{so} & \text{and} & \phi < 0 \end{array} \quad (2)$$

and

$$|i_G| \leq i_o - \Delta i_G = \frac{1}{N_G} |(i_B N_B - i_{so} N_S)|$$

$$\begin{array}{llll} \text{for} & i_s = -i_{so} & \text{and} & \phi > 0 \\ \text{and} & i_s = +i_{so} & \text{and} & \phi < 0. \end{array}$$

At the closing of the switch, the time $t = 0$, $i_s = +i_{so}$ and $\phi = 0$; i_G jumps instantaneously to the value

$$i_G = -\frac{1}{N_G} (i_B N_B - i_{so} N_S) = -(i_0 - \Delta i_G). \quad (3)$$

The current remains at this value for the time that $-\phi_s < \phi < 0$.

With $R = 0$ the gate circuit voltage equation is

$$V_c + V_i = 0, \quad (4)$$

where V_i, the voltage across the current saturable inductance, and V_c, the voltage across the capacitor, are

$$V_c = V_{co} + \frac{1}{c} \int^t i_G dt$$

$$= V_{co} - \frac{1}{c} \int_0^t (i_o - \Delta i_G) dt = V_{co} - \frac{1}{c} (i_o - \Delta i_G) t \quad (5)$$

and

$$V_i = N_G \frac{d\phi}{dt}. \quad (6)$$

Substituting Eqs. 5 and 6 in Eq. 4 and integrating,

$$-N_G\phi = V_{co}t - \frac{1}{2c}(i_o - \Delta i_G)t^2 \tag{7}$$

and

$$t = \frac{c}{i_o - \Delta i_G}\left[V_{co} \pm \sqrt{V_{co}^2 + \frac{2}{c}N_G\phi(i_o - \Delta i_G)}\right]. \tag{8}$$

Substituting Eq. 8 in Eq. 5 and eliminating t, we obtain a relationship between V_c and ϕ,

$$V_c^2 = V_{co}^2 + \frac{2}{c}N_G(i_o - \Delta i_G)\phi. \tag{9}$$

Equation 9 can be further simplified by defining

$$\phi = \phi_{o2} < 0 \qquad \text{at} \qquad V_c = 0. \tag{10}$$

Hence from Eq. 9

$$V_{co}^2 = -\frac{2N_G}{c}(i_o - \Delta i_G)\phi_{o2}; \qquad \phi_{o2} = -\frac{V_{co}^2 c}{2N_G(i_o - \Delta i_G)} \tag{11}$$

and

$$V_c^2 = \frac{2N_G}{c}(i_o - \Delta i_G)(\phi - \phi_{o2}). \tag{12}$$

Equation 12 represents a parabola in the V_c–ϕ plane (Fig. 4) and describes the operation in the half plane corresponding to $\phi < 0$. The

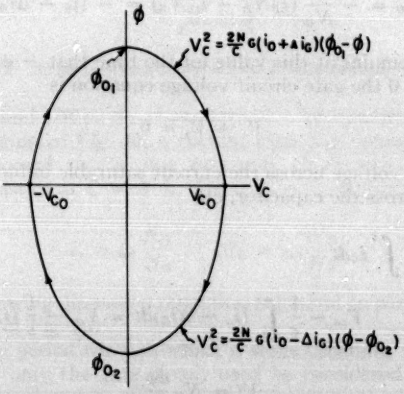


FIG. 4. Trajectories of the oscillations for $i_s = i_{so}$.

parabola crosses the V_c-axis at $V_c = V_{co}$ at the time corresponding to $t = 0$ and $V_c = -V_{co}$ at the time T_2 corresponding to:

$$t = T_2 = \frac{2V_{co}C}{i_o - \Delta i_G} \tag{13}$$

or by substituting the value of V_{co} from (11)

$$T_2^2 = -\left(\frac{2C}{i_o - \Delta i_G}\right)^2 \frac{2N_G(i_o - \Delta i_G)}{C}\phi_{o2} - \frac{-8N_G C\phi_{o2}}{i_o - \Delta i_G}. \tag{14}$$

T_2 is the period of the negative half cycle. Subsequently, positive current will tend to flow. Again the current charging the capacitor is limited and as ϕ will change from negative to positive value, the current will jump from

$$i_G = -(i_o - \Delta i_G) \tag{3}$$

to

$$i_G = i_o + \Delta i_G. \tag{15}$$

The operation may again be described by a parabola in the upper half of the V_c–ϕ plane. Equations similar to (9) and (12) can be written for the operation at $\phi > 0$. These will have the form of

$$V_c^2 = V_{co}^2 - \frac{2N_G}{C}(i_o + \Delta i_G)\phi. \tag{16}$$

Again at $V_c = 0$; $\phi = \phi_{o1} > 0$

$$V_{co}^2 = \frac{2N_G}{C}(i_o + \Delta i_G)\phi_{o1}; \quad \phi_{o1} = \frac{V_{co}^2 C}{2N_G(i_o + \Delta i_G)}. \tag{17}$$

Equation 16 can be written in the form

$$V_c^2 = \frac{2N_G}{C}(i_o + \Delta i_G)(\phi_{o1} - \phi). \tag{18}$$

The time required for the completion of the cycle, that is, for V_c to return from $-V_{co}$ to V_{co} is found similarly.

$$T_1 = \frac{2V_{co}C}{i_o + \Delta i_G}. \tag{19}$$

As long as $i_s = +i_{so}$ the operation is described by the combination of the two parabolas in the V_c–ϕ plane as shown in Fig. 4. The period of the oscillations is:

$$T = T_1 + T_2 = 2V_{co}C\left[\frac{1}{i_o - \Delta i_G} + \frac{1}{i_o + \Delta i_G}\right] = \frac{4V_{co}Ci_o}{i_o^2 - \Delta i_G^2}. \quad (20)$$

Figure 4 describes the operation in the V_c–ϕ plane while $i_s = +i_{so}$. For $i_s = -i_{so}$, new expressions may be written directly from the above equations by replacing Δi_G by $-\Delta i_G$.

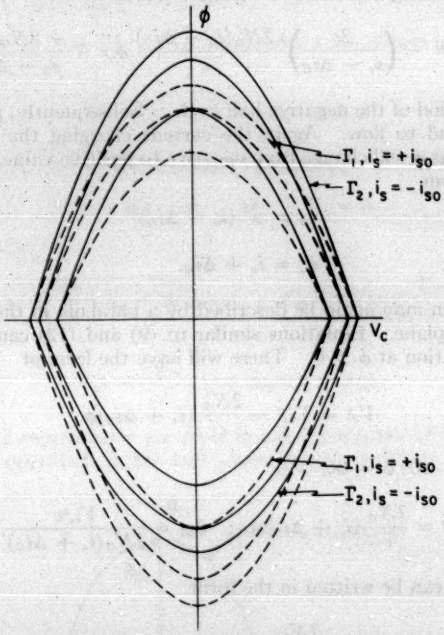


FIG. 5. Γ_1 and Γ_2 families of trajectories.

There will exist two families of trajectories in the V_c–ϕ plane which the operation must follow. Each trajectory is defined by the values of $\pm V_{co}$ at which it crosses the V_c-axis. Let the first family be Γ_1 (at $i_s = i_{so}$) defined as (same as Eqs. 9 and 16)

$$\begin{aligned} V_c^2 &= V_{co}^2 - \frac{2N_G}{C}(i_o + \Delta i_G)\phi \qquad \text{for} \qquad \phi > 0 \\ V_c^2 &= V_{co}^2 + \frac{2N_G}{C}(i_o - \Delta i_G)\phi \qquad \text{for} \qquad \phi < 0. \end{aligned} \quad (21)$$

The second family of trajectories Γ_2 (at $i_s = -i_{so}$) is defined as

$$V_c^2 = V_{co}^2 - \frac{2N_G}{c}(i_o - \Delta i_G)\phi \qquad \text{for} \qquad \phi > 0$$
$$V_c^2 = V_{co}^2 + \frac{2N_G}{c}(i_o + \Delta i_G)\phi \qquad \text{for} \qquad \phi < 0. \tag{22}$$

The two families of trajectories are shown in Fig. 5.

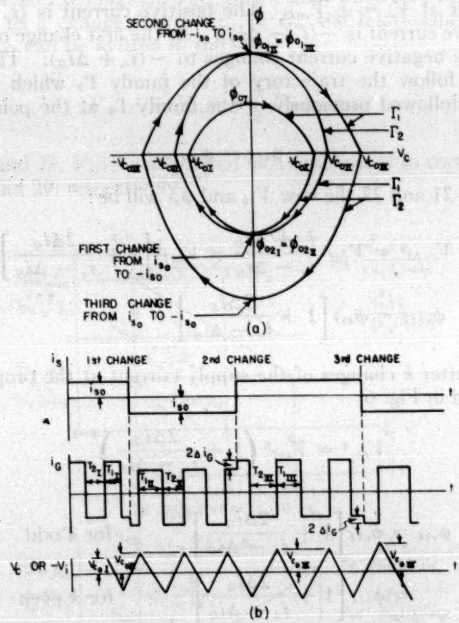


FIG. 6. Description of operation at special case $R = 0$.

At the instant of the change from $i_s = +i_{so}$ to $i_s = -i_{so}$, or *vice versa*, the point of operation will exchange trajectories. After the instant of the change in the supply current, the point of operation will move along a trajectory belonging to the other family than the trajectory followed before the change of current. At the instant of change in the supply current, V_c and ϕ cannot change instantaneously. Hence, the two trajectories intersect at the point which corresponds to the instant of change of the supply current.

To illustrate this, let us consider a special case. Let the first change be from i_{so} to $-i_{so}$ at $V_c = 0$ and $\phi = \phi_{o2} = \phi_{\min} < 0$. The next change from $-i_{so}$ to i_{so} will occur several cycles later at $V_c = 0$; $\phi_{o1} = \phi_{\max} > 0$. This process will repeat itself several times. The operation in such a case is described in Fig. 6 and explained in the following:

Let $V_c = V_{coI}$ and $\phi = 0$ at time $t = 0$. The operation follows a trajectory of the family Γ_1 which is a combination of two parabolas which meet at $V_c = \pm V_{coI}$. The positive current is $(i_o + \Delta i_G)$ and the negative current is $-(i_o - \Delta i_G)$. At the first change of the supply current the negative current changes to $-(i_o + \Delta i_G)$. The operating point will follow the trajectory of the family Γ_2 which touches the trajectory followed previously of the family Γ_1 at the point $(\phi_{o2I}; 0)$. Hence,

$$\phi_{o2I} = \phi_{o2II}. \tag{23}$$

From Eqs. 21 and 22 the new V_{co} and ϕ_{o1} will be:

$$\begin{aligned} V_{coII}^2 &= V_{coI}^2 \frac{i_o + \Delta i_G}{i_o - \Delta i_G} = V_{coI}^2 \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right] \\ \phi_{o1II} &= \phi_{o1I} \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right]. \end{aligned} \tag{24}$$

Similarly, after k changes of the supply current at the proper instants as described in Fig. 6,

$$V_{co_k}^2 = V_{coI}^2 \left(1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right)^{k-1} \tag{25}$$

and

$$\begin{aligned} \phi_{o1k} &= \phi_{o1I} \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right]^{(k-1)} && \text{for } k \text{ odd} \\ &= \phi_{o1I} \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right]^{k} && \text{for } k \text{ even} \end{aligned} \tag{26}$$

$$\begin{aligned} \phi_{o2k} &= \phi_{o2I} \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right]^{k-1} && \text{for } k \text{ odd} \\ &= \phi_{o2I} \left[1 + \frac{2\Delta i_G}{i_o - \Delta i_G}\right]^{k-2} && \text{for } k \text{ even.} \end{aligned} \tag{27}$$

The area enclosed by the two parabolas describing a cycle of the oscillations of gate circuit increases with each change of supply current.

Let us consider the more general case where the change in current occurs at a point $(V_{c_e}; \phi_e)$. Consider first an exchange of trajectories

from family Γ^1 to family Γ_2 which correspnods to a change from i_{so} to $-i_{so}$. Equations 21 and 22 are equated at the point $(V_c; \phi_c)$. Let the V_{co} before and after the change of supply current be again V_{coI} and V_{coII}, respectively. Hence,

$$V_{coII}^2 = V_{coI}^2 - \frac{4}{C} N_G \Delta i_G \phi_c. \tag{28}$$

Similarly, for an exchange of trajectories from family Γ_2 to Γ_1, which corresponds to a change from $-i_{so}$ to i_{so}, the relationship between V_{coI} and V_{coII} can be written in the form

$$V_{coII}^2 = V_{coI}^2 + \frac{4}{C} N_G \Delta i_G \phi_c. \tag{29}$$

In Figs. 7*a* and 7*b*, V_{coII}^2 was plotted as a function of ϕ_c corresponding to Eqs. 28 and 29, respectively.

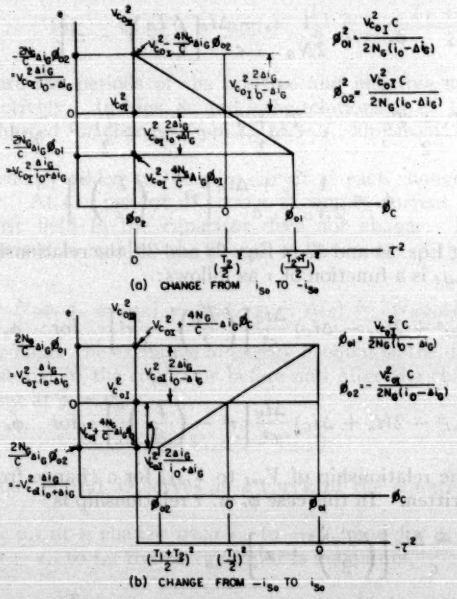


FIG. 7. Maximum voltage across capacitor^2 $(V_{co})^2$ and energy gain after supply current change (ϵ) vs flux at instant of change (ϕ_c) and phase^2 (τ^2).

The relationship of V_{coI} and V_{coII} can be determined as a function of the phase, that is, the time in each cycle at which the change in i_s occurs with respect to the oscillations of the gate circuit current. Thus let the phase be τ, with $\tau = 0$ corresponding to the instant when $\phi = \phi_{o2}$ for a change in i_s from $+ i_{so}$ to $- i_{so}$, and corresponding to the instant when $\phi = \phi_{o1}$ for a change in i_s from $- i_{so}$ to i_{so}. From Eqs. 8 and 13, the phase τ corresponds to the time t_c, at which the change in supply current occurs.

$$\tau = t_c - \frac{T_2}{2} = \frac{c}{i_o - \Delta i_G}\left[V_{co} \pm \sqrt{V_{co}^2 + \frac{2}{c} N_G (i_o - \Delta i_G)\phi_c}\right] - \frac{V_{co}c}{i_o - \Delta i_G}$$

$$= \pm \frac{c}{i_o - \Delta i_G}\sqrt{V_{co}^2 + \frac{2}{c} N_G (i_o - \Delta i_G)\phi_c}. \quad (30)$$

Equation 30 holds for a change from i_{so} to $- i_{so}$, at $-\frac{T_2}{2} < \tau < \frac{T_2}{2}$ and $\phi_c < 0$. Hence, using Eq. 13,

$$\phi_c = -\frac{1}{2N_G}\frac{i_o - \Delta i_G}{c}\left[\left(\frac{T_2}{2}\right)^2 - \tau^2\right]. \quad (31)$$

Similarly, for

$$\frac{T_1}{2} < \tau < \frac{T_1 + T_2}{2}, \qquad -\frac{T_1 + T_2}{2} < \tau < -\frac{T_1}{2} \qquad \text{and} \qquad \phi_c > 0,$$

$$\phi_c = \frac{1}{2N_G}\frac{i_o + \Delta i_G}{c}\left[\tau^2 - \left(\frac{T_1}{2}\right)^2\right]. \quad (32)$$

Substituting Eqs. 31 and 32 in Eqs. 28 and 29, the relationship between V_{coI} and V_{coII} is a function of τ as follows:

$$V_{coII}^2 = V_{coI}^2 + 2(i_o - \Delta i_G)\frac{\Delta i_G}{c^2}\left[\left(\frac{T_2}{2}\right)^2 - \tau^2\right] \quad \text{for} \quad \phi_c < 0 \quad (33)$$

and

$$V_{coII}^2 = V_{coI}^2 - 2(i_o + \Delta i_G)\frac{\Delta i_G}{c^2}\left[\tau^2 - \left(\frac{T_2}{2}\right)^2\right] \quad \text{for} \quad \phi_c > 0. \quad (34)$$

Similarly, the relationship of V_{coI} to V_{coII} for a change from $- i_{so}$ to i_{so} can be written. In this case ϕ_c *vs.* τ relationship is

$$\phi_c = \frac{1}{2N_G}\frac{i_o - \Delta i_G}{c}\left[\left(\frac{T_1}{2}\right)^2 - \tau^2\right] \quad (35)$$

$$\text{for} \quad \phi_c > 0 \quad \text{and} \quad -\frac{T_1}{2} < \tau < \frac{T_1}{2}$$

and

$$\phi_c = \frac{1}{2N_G}\frac{i_o + \Delta i_G}{c}\left[\tau^2 - \left(\frac{T_1}{2}\right)^2\right]$$

$$\text{for} \quad \phi_c < 0 \quad \text{and} \quad \frac{T_1}{2} < |\tau| < \frac{T_1 + T_2}{2} \tag{36}$$

and the relationship between V_{coI} and V_{coII} as a function of τ is

$$V_{coII}^2 = V_{coI}^2 + 2(i_o - \Delta i_G)\frac{\Delta i_G}{c^2}\left[\left(\frac{T_1}{2}\right)^2 - \tau^2\right]$$

$$\text{for} \quad \phi_c > 0 \quad \text{and} \quad |\tau| < \frac{T_1}{2} \tag{37a}$$

and

$$V_{coII}^2 = V_{coI}^2 - 2(i_o + \Delta i_G)\frac{\Delta i_G}{c^2}\left[\tau^2 - \left(\frac{T_1}{2}\right)^2\right]$$

$$\text{for} \quad \phi_c < 0 \quad \text{and} \quad \frac{T_1}{2} < \tau < \frac{T_1 + T_2}{2} \tag{37b}$$

T_1 and T_2 are the periods of the positive and negative current half cycles, respectively. In Figs. 8*a* and *b* the relationship of V_{coII} *vs.* the phase τ is charted for changes from i_{so} to $-i_{so}$ and from $-i_{so}$ to i_{so}, respectively.

Let the energy added to the gate circuit at each change of supply current be e. At the instant of change of supply current the energy of the electric field in the capacitor does not change. Hence, the energy exchanged is equal to the change of the energy of the magnetic field.

$$e = N_G\phi_c(i_o + \Delta i_G) - N_G\phi_c(i_o - \Delta i_G) = 2N_G\phi_c\Delta i_G. \tag{38}$$

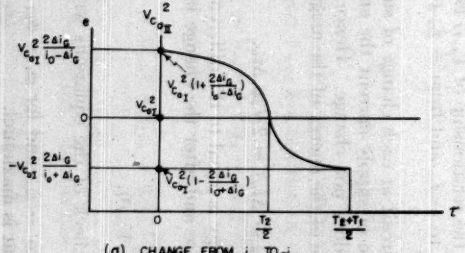
On the other hand, the exchange of energy is equal to the difference in the energy stored in the capacitor before and after the change in the supply current at $\phi = 0$.

$$e = \tfrac{1}{2}c(V_{coII}^2 - V_{coI}^2). \tag{39}$$

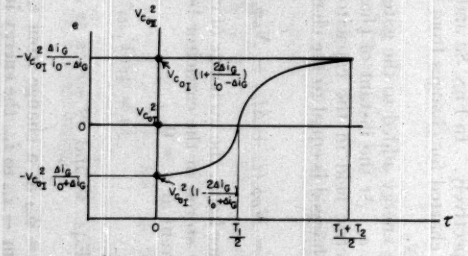
Equating Eqs. 38 and 39 serves as a check of the equations written so far.

For $\phi_c = \phi_{o2}$ at a change from i_{so} to $-i_{so}$, and for $\phi_c = \phi_{o1}$ at a change from $-i_{so}$ to i_{so}, the energy input is maximum.

$$e_{max} = 2\Delta i_G N_G\phi_{o1 \text{ or } 2} = V_{coI}^2 c\frac{\Delta i_G}{i_o - \Delta i_G}. \tag{40}$$

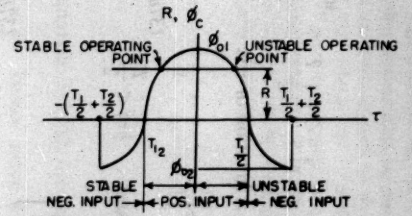


(a) CHANGE FROM i_{so} TO $-i_{so}$

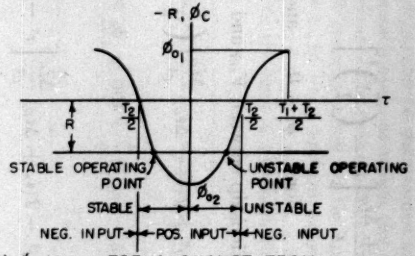


(b) CHANGE FROM $-i_{so}$ TO i_{so}

FIG. 8. Maximum voltage across capacitor[8] ($V_{c_o}^2$) and energy gain after supply current change (e) *vs* phase (τ).



(a) ϕ_C Vs. τ FOR A CHANGE FROM $-i_{so}$ TO i_{so}



(b) ϕ_C Vs. τ FOR A CHANGE FROM i_{so} TO $-i_{so}$

FIG. 9.

Figures 7 and 8 show the relationship of e to ϕ_c, τ^2 and τ for the different cases involved. Figure 9 shows the relationship of ϕ_c *vs.* τ. The shaded areas in Fig. 10 represent, according to Eq. 38, the gain of energy at a change of the supply current.

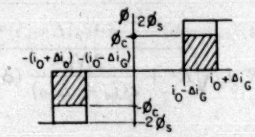


FIG. 10. Energy gains at changes in supply current.

4. THE CASE OF $R \neq 0$, BALANCE OF ENERGY

In the case described in Fig. 6 the magnetic energy of the gate circuit increases each time the supply current changes. As there is no output of energy, the energy of the gate circuit keeps increasing. As a result, the period of each oscillation of the gate circuit current increases and hence, also the period of the supply current would have to increase which is not practical. It is of practical interest to consider a system where the energy input will be balanced by energy output. In such a system also the average period of the oscillations of the gate circuit current and the period of the supply circuit current will be constant throughout the operation of the circuit. The output of energy is into the resistance in the gate circuit ($R \neq 0$). By considerations of balance of input and output energy the output into the resistance will be determined.

The effect of $R \neq 0$ on the operation of the circuit of Fig. 1 will be considered first. The following discussion of the operation of this circuit is also illustrated in Figs. 11*a* and *b* for a frequency multiplication of $n = 3$.

The gate circuit equation for $R \neq 0$ is

$$V_i + V_R + V_c = 0. \tag{41}$$

V_R, the voltage across the resistance in the gate circuit, is

$$V_R = Ri_G. \tag{42}$$

V_i is the same as in Eq. 6.

Let $t = 0$ be the instant when $V_c = 0$; $\phi = \phi_{o1} > 0$, $i_s = i_{so}$ and $i_G = i_o + \Delta i_G$. Then V_c will be:

$$V_c = \frac{1}{c}\int_0^t (i_o + \Delta i_G)dt = \frac{1}{c}(i_o + \Delta i_G)t. \tag{43}$$

Substituting these values of V_R, V_i and V_e in Eq. 41 and integrating with respect to t,

$$N_G(\phi_{o1} - \phi) = \left(\frac{1}{2c}t^2 + Rt\right)(i_o + \Delta i_G). \tag{44}$$

Hence,

$$t = c\left[-R \pm \sqrt{R^2 + \frac{2N_G}{c(i_o + \Delta i_G)}(\phi_{o1} - \phi)}\right]. \tag{45}$$

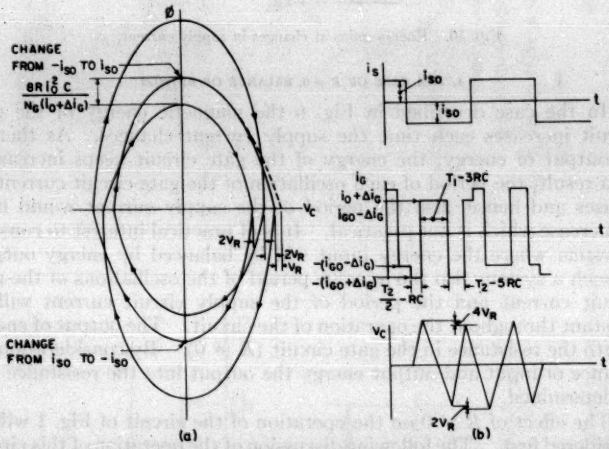


FIG. 11. Operation at $n = 3$, $R \neq 0$, $V_R \ll V_{c_0}$.

The plus sign is used at $t > -RC$ and the minus sign is used at $t < -RC$. At $t = -RC$ the flux attains its maximum,

$$\phi_{\max} = \frac{R^2c(i_o + \Delta i_G)}{2N_G} + \phi_{o1}. \tag{46}$$

Substituting Eq. 45 in Eq. 43, t is eliminated and the V_e *vs.* ϕ relationship is determined:

$$V_e = -R(i_o + \Delta i_G) \pm \sqrt{R^2(i_o + \Delta i_G)^2 + \frac{2N_G}{c}(\phi_{o1} - \phi)(i_o + \Delta i_G)}$$

$$= -V_R' \pm \sqrt{V_R'^2 + \frac{2N_G}{c}(\phi_{o1} - \phi)(i_o + \Delta i_G)}. \tag{47}$$

Again the plus sign is used for $t > -RC$ and the minus sign for $t < -RC$. At $t = -RC$, $V_c = 0$.

An expression similar to Eq. 47 can be developed for $\phi < 0$; $i_s = +i_{so}$. This will be

$$V_c = R(i_o - \Delta i_G) \pm \sqrt{R^2(i_o - \Delta i_G)^2 + \frac{2N_G}{c}(\phi - \phi_{o2})(i_o - \Delta i_G)}$$

$$= V_R \pm \sqrt{V_R^2 + \frac{2N_G}{c}(\phi - \phi_{o2})(i_o - \Delta i_G)}. \quad (48)$$

Again the instant at which $V_c = 0$, $\phi = \phi_{o2} < 0$ is denoted as $t = 0$. Then the plus sign is used in Eq. 48 for $t > -RC$ and the minus sign for $t < -RC$.

Expressions similar to Eqs. 47 and 48 can be written for the case of $i_s = -i_{so}$ by exchanging Δi_G for $-\Delta i_G$.

Equations 47 and 48 describe the trajectories of the operation in the positive and negative halves of the V_c–ϕ planes. At the points $\phi = 0$, the operating point exchanges the trajectory from that of Eq. 47 to that of Eq. 48 or *vice versa* without changing the voltage across the capacitor. For a change from $\phi > 0$ to $\phi < 0$ or from $i_G > 0$ to $i_G < 0$, equating V_c in Eqs. 47 and 48 results in

$$2Ri_o = \sqrt{V_R^2(\phi > 0) + \frac{2N_G}{c}\phi_{o1I}(i_o + \Delta i_G)}$$

$$- \sqrt{V_R^2(\phi < 0) - \frac{2N_G}{c}\phi_{o2I}(i_o - \Delta i_G)} \quad (49)$$

and, for a change from $\phi < 0$ to $\phi > 0$,

$$2Ri_o = \sqrt{V_R^2(\phi < 0) - \frac{2N_G}{c}\phi_{o2I}(i_o - \Delta i_G)}$$

$$- \sqrt{V_R^2(\phi > 0) + \frac{2N_G}{c}\phi_{o1II}(i_o + \Delta i_G)} \quad (50)$$

where ϕ_{o1I}, ϕ_{o1II} and ϕ_{o2I}, ϕ_{o2II} are the fluxes at $V_c = 0$ at $\phi > 0$ and $\phi < 0$ in two successive cycles of the gate circuit current respectively. Summing up Eqs. 49 and 50:

$$Ri_o = \tfrac{1}{4}\left[\sqrt{VR^2(\phi > 0) + \frac{2N_G}{c}\phi_{o1I}(i_0 + \Delta i_G)}\right.$$

$$\left. - \sqrt{V_R^2(\phi > 0) + \frac{2N_G}{c}\phi_{o1II}(i_o + \Delta i_G)}\right]. \quad (51)$$

From Eqs. 45 through 51 it can be shown that ϕ_{o1}, ϕ_{o2}, T_1, T_2, and V_{co} decrease each cycle of the gate circuit current. For $V_R \neq 0$, the trajectories become a kind of spiral approaching the origin.

For $V_R \ll V_{co}$, V_R^2 can be neglected in comparison with V_{co}^2, or $\frac{2N_G}{C}\phi_{o1 \text{ or } 2}$ (see Eq. 11). When this approximation is applied to Eqs. 47 and 48 it becomes apparent that V_{co} decreases by approximately $4V_R$ per cycle of the gate circuit current. This can be put in the form

$$V_{coII} = V_{coI} - 4V_{R\text{average}} = V_{coI} - 4Ri_o \tag{52}$$

$$\sqrt{\phi_{o1II}} = \sqrt{\phi_{o1I}} - \frac{4V_{R\text{average}}}{\frac{\sqrt{2N_G(i_o + i_G)}}{C}}, \tag{53}$$

where V_{coI} and V_{coII} are the voltages across the capacitor at $\phi = 0$ in two successive cycles, respectively.

Applying the same approximations to Eq. 45 shows that T_1 and T_2 decrease approximately by $2\,RC$ per cycle of gate circuit current.

The supply current reverses polarity each $n/2$ cycles of gate circuit current (n is an odd integer). As shown in analyzing the case of $R = 0$, the gate circuit receives as a result a pulse of energy. The considerations regarding this pulse of energy hold for the $R \neq 0$ as well. Equation 40 gives the energy transferred into the gate circuit at each reversal of polarity of the supply current. It is apparent from Fig. 7 that in order for power to be transferred to the gate circuit, $\phi_o < 0$ for a change from i_{so} to $-i_{so}$; and $\phi_c > 0$ for a change from $-i_{so}$ to i_{so}. Otherwise, power will be withdrawn instead of being inserted. If ϕ_c satisfies these conditions and has the same value at each change of supply current, then the power transferred is

$$P = 4N_G|\phi_c|\Delta i_G f_o \tag{54}$$

where f_o is the frequency of the supply current and n is the frequency multiplicand. Equating the input and output powers gives the balance of energy:

$$4N_G|\phi_c|\Delta i_G f_o = R[\tfrac{1}{2}(i_o + \Delta i_G)^2 + \tfrac{1}{2}(i_o - \Delta i_G)^2] = R(i_o^2 + \Delta i_G^2). \tag{55}$$

In order to have minimum supply frequency current component in the gate circuit, Δi_G is kept small. $N_G|\phi_c|$ can be increased at an expense in cost of windings and iron. It is significant that the power in the gate circuit does not depend on the multiplicand of frequency (except for the hysteresis loss which has been neglected so far).

As an example suppose that it is required to multiply the frequency by m instead of by n, where m is another odd integer. If the load is the same, ϕ_{o1}, ϕ_{o2}, ϕ_e and Δi_G may be the same. From Eq. 20 it may be seen that $T_1 + T_2$ is directly proportional to $V_{co}c$. Hence, in order to achieve a multiplication of frequency by m instead of n, V_{co} will be changed in the ratio of m/n and c in the ratio of $(n/m)^2$. Hence, the equipment for higher multiplication of frequency will have to withstand proportionally higher voltages.

The saturation flux, ϕ_s, imposes a limitation on the maximum permissible resistance R. At the maximum energy transfer condition, $\phi_e = \phi_s$. Then from Eq. 55:

$$R_{\max} < \frac{8N_G f_o \Delta i_G \phi_s}{i_o^2}. \tag{56}$$

5. STABILITY

It has been shown in the preceding section that oscillations can be maintained under balanced conditions of input and output power. The next question now is whether this balance is a stable one. Assume that a small disturbance is introduced in the timing of the supply current and gate circuit oscillations. The balance of power would then be disturbed. Stability would require that subsequent to the introduction of the disturbance the operation would return automatically to the initial timing and amplitudes that correspond to the power balance conditions.

Assume that a steady state operation with the output and input powers balanced has been achieved. The operation is described in the ϕ–V_e plane by a trajectory of which the origin is circled n times per supply cycle. This type of operation is described for $n = 3$ in Fig. 11. The changes of the supply current occur at $\phi = \phi_e$ and at phase τ. For a change from i_{so} to $-i_{so}$, $\tau = 0$ corresponds to the instant when $V_e = 0$, $\phi = \phi_{o2}$. For a change from $-i_{so}$ to $+i_{so}$, $\tau = 0$ corresponds to the instant when $V_e = 0$, $\phi = \phi_{o1}$. The ϕ_e *vs.* τ relationship is given in Eqs. 32 and 35 and is shown in Fig. 9.

A disturbance is introduced in the steady state operation in the form of a change of supply current at $\phi_e' = \phi_e + \Delta\phi$ and $\tau' = \tau + \Delta\tau$ (instead of at ϕ_e and τ which are required by the balance of energy). $|\Delta\phi|$ and $|\Delta\tau|$ will be examined in subsequent cycles. If $\Delta\phi$ and $\Delta\tau$ tend to zero with time or remain small the operation will be stable. Otherwise, it will be unstable.

As $\Delta\tau$ and $\Delta\phi$ are related one to another, as indicated in Eqs. 32 and 35, it is sufficient to analyze the behavior of $\Delta\tau$. The change in τ effects the periods of the oscillations in the gate current. Let α_1, $\alpha_2 \cdots \alpha_K \cdots \alpha_n$ be the periods of the successive half cycles of the gate circuit current subsequent to the change of the supply current. The

condition of balance of energy requires that n half cycles of the gate circuit current correspond to half a cycle of the supply current:

$$[\sum_{K=1}^{n} \alpha_K]_\tau = \tfrac{1}{2}\text{cycle period of the supply current.} \tag{57}$$

If α_K changes in such a way that the phase τ' tends to be corrected to τ, the operation will be stable. The condition that $|\Delta\tau|$ decreases each half cycle of the supply current can be stated as follows:
For $\Delta\tau$ positive

$$2\Delta\tau > [\sum_{K=1}^{n} \alpha_K]_\tau - [\sum_{K=1}^{n} \alpha_K]_{\tau'} > 0. \tag{58}$$

For $\Delta\tau$ negative

$$-2\Delta\tau > [\sum_{K=1}^{n} \alpha_K]_{\tau'} - [\sum_{K=1}^{n} \alpha_K]_\tau > 0. \tag{59}$$

(58) and (59) can be written for $\Delta\tau$ very small in the form (by the mean value theorem)

$$2 > \frac{d}{d\tau}[\sum_{K=1}^{n} \alpha_K] > 0. \tag{60}$$

From Eq. 45 for R small, the following approximation can be made:

$$\alpha_K = \alpha_{K+2} - 4RC. \tag{61}$$

The difference between α_K and α_{K+2} is a constant and independent of τ. These constants can be eliminated from the criterion of stability (60) which can be set in terms of the half cycle periods of oscillations in the gate circuit at $R = 0$, namely, T_1 and T_2:

$$\sum_{K=1}^{n} \alpha_K = \frac{n}{2}(T_1 + T_2) + \text{constant}. \tag{62}$$

Then (60) can be stated as follows:

$$\frac{4}{n} > \frac{d}{d\tau}(T_1 + T_2) > 0. \tag{63}$$

Substituting Eq. 20 in 63,

$$\frac{4}{n} > \frac{d}{d\tau}\left(\frac{4V_{cc}Ci_o}{i_o^2 - \Delta i_G^2}\right) > 0. \tag{64}$$

Let V_{coI} and V_{coII} be the values of V_{co} at $\phi = 0$ before and after the change in supply current, respectively ($R = 0$). V_{coI} is independent of τ while V_{coII} varies with τ.

Equations 33 and 37 hold for the period in which there can be positive energy input into the gate circuit. From these equations,

$$\frac{dV_{coII}}{d\tau} = -4(i_o - \Delta i_G)\frac{\Delta i_G}{c^2}\tau. \tag{65}$$

Also

$$\frac{1}{2V_{coII}}\frac{d}{d\tau}(V_{coII}^2) = \frac{dV_{coII}}{d\tau}. \tag{66}$$

Substituting Eqs. 65 and 66 in Eq. 64, the criterion of stability takes the form

$$\frac{1}{n} > \frac{-2\Delta i_G i_o}{V_{coII}(i_o + \Delta i_G)c}\tau > 0. \tag{67}$$

On the other hand the requirement of a positive power input to the gate circuit is satisfied for $-\frac{T_{1\text{ or }2}}{2} < \tau < \frac{T_{1\text{ or }2}}{2}$ only (Fig. 9). Both conditions of positive power input and stability are satisfied for

$$\begin{aligned} &> \frac{-T_{1\text{ or }2}}{2} \\ 0 &> \tau \\ &> -V_{coI}c(i_o + \Delta i_G)/2\Delta i_G i_o n. \end{aligned} \tag{68}$$

From Eqs. 20, 33 and 37, the dependence of $T_1 + T_2 \left(\approx \frac{i}{f_o n}\right)$ on τ can be determined.

$$T_1 + T_2 = \frac{4\Delta i_G i_o}{V_{coI}(i_o + \Delta i_G)c}\tau^2 + \text{constant}. \tag{69}$$

The plot of Eq. 69 with the stable and unstable regions marked is shown in Fig. 12.

In the above considerations the disturbance $\Delta\tau$ has been taken as very small. It is obvious, however, that in order to satisfy (60), $\Delta\tau$ should not exceed such values that will cause τ not to satisfy the conditions of (68). This condition will be certainly satisfied if $\Delta\tau$ is bounded by $<|\tau|$

$$\begin{aligned} |\Delta\tau| &< \frac{T_{1\text{ or }2}}{2} - |\tau| \\ &< (T_1 + T_2)i_o/8n\Delta i_G - |\tau|. \end{aligned} \tag{70}$$

The above conclusions are summed up in Figs. 9*a* and *b* where the situation is described for a change from $-i_{s_0}$ to $+i_{s_0}$ and from $+i_{s_0}$ to $-i_{s_0}$, respectively. The stable and unstable regions as well as the regions of positive and negative power input to the gate circuit are shown in Fig. 9. From Eq. 54, the resistance in the gate circuit (R) is proportional to ϕ_c. Hence, the ϕ_c *vs.* τ plot can be the R *vs.* τ plot as well, to a different scale. Drawing the R = constant line gives the points of operation, one of which falls in the stable region.

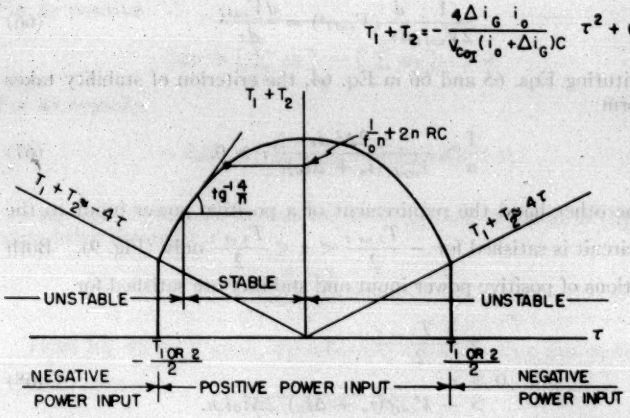


FIG. 12. Conditions of stability.

6. EXCITATION OF OSCILLATIONS

The oscillations will start from any point on the required trajectory of the ϕ–V_c plane. It would be better to start the oscillations from a point farther from the origin than the points of the required trajectory. After a short transient period operation may arrive at steady state as shown in the discussion of stability.

One manner of excitation is to charge the capacitor to a value well beyond V_{c_0} and then close the switch of the gate circuit. Hence, the operation will start from a point corresponding to $\phi = 0$. It is also possible to excite the oscillations from a point of $V_{c_0} = 0$, $\phi \geqslant 2\phi_S$. This can be done by a special excitation winding that magnetizes both cores in the same direction beyond saturation. Oscillations will commence upon opening the circuit of the excitation winding. It has been found experimentally that a momentary increase of i_{s_0}, or a momentary decrease of i_B, so that

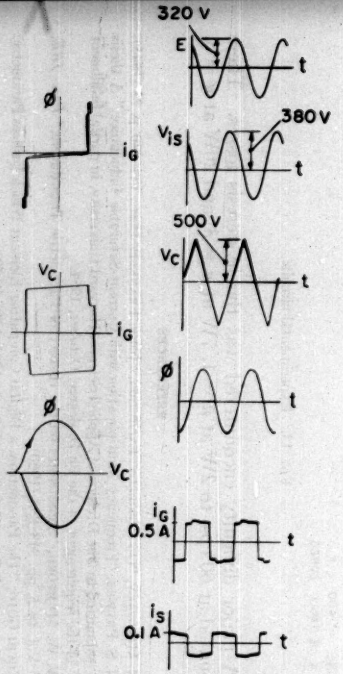


FIG. 14. Operation with the circuit of Fig. 13 at $n = 1$, $i_o = 5A$, $\Delta i_G = 025A$, $C = .4\mu f$, $V_{c_o} = 500V$.

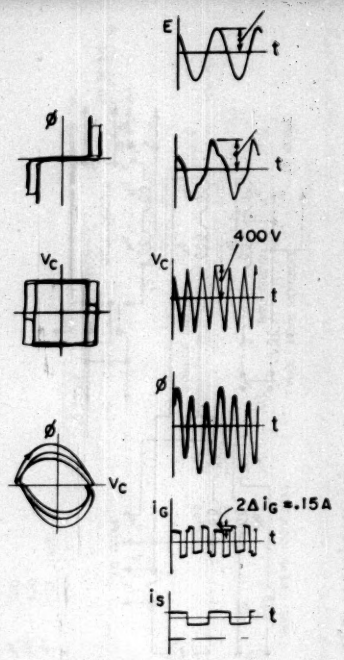


FIG. 15. Operation with the circuit of Fig. 13 at $n = 3$, $i_o = 5A$, $\Delta i_G = 075A$, $C = 1.5\mu f$, $V_{c_o} = 400V$.

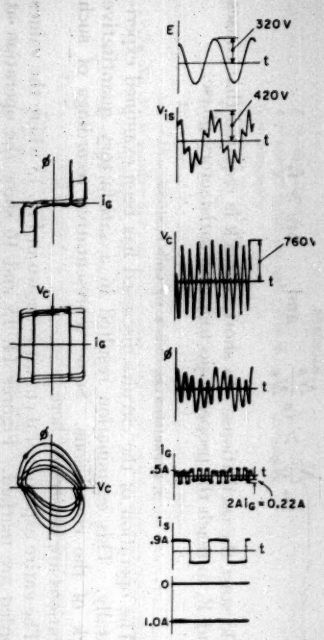


FIG. 16. Operation with the circuit of Fig. 13 at $n = 5$, $i_o = .5A$, $\Delta i_G = .11A$, $C = .5\mu f$, $V_{c_o} = 760V$.

$$i_{s_0}\frac{N_s}{N_G} > i_B\frac{N_B}{N_G} \quad \text{and} \quad \Delta i_G > i_c$$

would start the oscillations. In short, a shock is required that causes ϕ and V_c to reach the proper trajectory at a satisfactory phase.

7. EXPERIMENTAL CHECK OF CONCLUSIONS

The operation of the circuits discussed has been examined experimentally. This examination resulted in a satisfactory quantitative check of the conclusions. Some representative recordings of such operations are illustrated here.

The entire experimental circuit is shown in Fig. 13 where the values recorded are marked. Figures 14, 15 and 16 show the operation at $n = 1, 2, 5$, respectively.

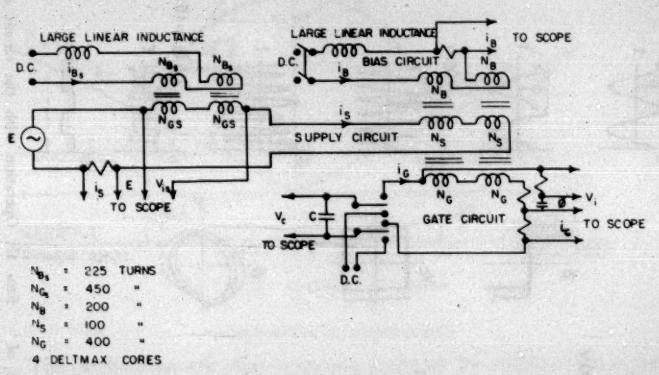


FIG. 13. Experimental circuit.

A major difficulty encountered was the hysteresis losses. These amounted at 60 cps. to 2W at $n = 1$, 7W at $n = 3$, and 20W at $n = 5$.

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SYMBOLS

c = capacitance
e = energy input per half cycle of supply frequency
f_s = frequency
i_B = base circuit current
i_G = gate circuit current
i_{so} = amplitude of square wave supply circuit current
Σi = sum of the ampere turns of the windings on one core
Δi_G = change in gate circuit current that corresponds to i_{so}
N_B, N_G, N_S = number of turns in bias, gate, and supply circuit windings, respectively
n = multiplicand of frequency
R = gate circuit resistance
P = power
T_1, T_2 = periods of positive and negative gate circuit current, respectively
t = time
t_e = time at which the supply circuit changes polarity
V_c = voltage across capacitor
V_{co} = voltage across capacitor at $\phi = 0$
$V_{co}I$, $V_{co}II$, etc. = values of V_{co} in successive cycles of gate circuit current or before and after change in supply circuit current
V_i = voltage across inductance in gate circuit
V_R = resistive voltage drop in the gate circuit
$V_R{}^+$ = $(i_o + \Delta i_G)R$
$V_R{}^-$ = $(i_0 - \Delta i_G)R$
$\alpha_1, \alpha_2 \ldots \alpha_n$ = periods of positive or negative gate circuit current
ϕ = flux
ϕ_e = flux at change of supply circuit current
ϕ_s = saturation flux
ϕ_{o1}, ϕ_{o2} = maximum positive and negative fluxes, respectively
$\phi_{o(1 \text{ or } 2)}I$, $\phi_{o(1 \text{ or } 2)}II$, etc. = $\phi_{o1 \text{ or } 2}$ in successive cycles of gate circuit current or before and after a change in supply circuit current
ϕ_1, ϕ_2 = fluxes in cores No. 1 and No. 2 of current saturable inductance, respectively
T = time, indicating phase

MEDAL DAY PROCEEDINGS AT THE FRANKLIN INSTITUTE

October 19, 1960

Reception and Dinner

On Wednesday, October 19, 1960, approximately 430 Institute members and guests gathered to pay tribute to the men whose achievements had been recognized by the Committee on Science and the Arts during the past year. A reception honoring the 1960 Medalists was held at 6:15 P.M. in the lobby of Franklin Hall, and at 7:00 P.M. the guests assembled for dinner in the Hall. The Reverend Doctor Frederick E. Maser, Rector of Old St. George's Church in Philadelphia, gave the invocation.

* * * *

During dinner, Wynn Laurence LePage, President of The Institute, thanked the members of the Hostess Committee for their assistance at the reception and for the floral decorations. Mr. LePage proposed the following toast to Benjamin Franklin:

"We have met here this evening for the special purpose of recognizing and honoring a selected group of men for outstanding achievement in the physical sciences.

"But, in this majestic hall, seeming to lend a blessing to the great educational development program upon which we are embarking, is the spirit of him in whose honor and memory this Institute was founded and to whom we remain dedicated. His genius, his wisdom and his enterprise always have and always will inspire us in our efforts.

"Ladies and Gentlemen: To Dr. Franklin."

* * * *

Mr. J. Philip Evans, Chairman of the Committee on Science and the Arts, introduced the following former Medalists who were present at the dinner.

FORMER MEDALISTS ATTENDING MEDAL DAY, 1960

Year Awarded	Medalist
SCOTT MEDAL (Founded 1816)	
1916	Dr. John V. N. Dorr
CRESSON MEDAL (Founded 1848)	
1903	Dr. G. H. Clamer
1944	Dr. Roger Adams
1953	Dr. William Blum
CERTIFICATE OF MERIT (Founded 1882)	
1921	Dr. Joseph S. Hepburn
1939	Mr. E. Burke Wilford
1942	Dr. John J. Grebe
LONGSTRETH MEDAL (Founded 1890)	
1911	Dr. Joseph S. Hepburn
1917	Mr. Alan Standish Dana
1923	Mr. Harry S. Parks
1936	Mr. Elmer A. Sperry, Jr.
1937	Mr. John S. Haug
1948	Mr. Nicholas F. Arone
1957	Dr. J. B. Johnson
1958	Dr. George S. Crampton
POTTS MEDAL (Founded 1906)	
1948	Dr. Clarence A. Lovell
1949	Mr. J. Presper Eckert, Jr.
1949	Dr. John W. Mauchly
LEVY MEDAL (Founded 1923)	
1939	Professor K. J. DeJuhasz
1945	Dr. Rupen Eksergian
1948	Dr. William H. Cherry
1951	Dr. Albert C. Walker
HENDERSON MEDAL (Founded 1925)	
1937	Dr. Rupen Eksergian
WETHERILL MEDAL (Founded 1925)	
1941	Dr. Harold S. Black
CLAMER MEDAL (Founded 1943)	
1950	Dr. Charles S. Barrett
1957	Mr. W. G. Pfann
BALLANTINE MEDAL (Founded 1946)	
1948	Mr. Ray D. Kell
1952	Dr. Walter H. Brattain
1956	Mr. Kenneth Bullington

MR. LEPAGE: "Thank you, Mr. Evans. Gentlemen, we are greatly honored by your presence. We hope that you will return again and again for you are, indeed, a part of The Franklin Institute.

"And now, Ladies and Gentlemen, is the moment for me to give well-earned recognition to the gentlemen of the Committee of which Mr. Evans is the distinguished Chairman. Within a year of its founding, in 1824, The Franklin Institute established within itself a Committee on Inventions. It was the duty of the members of this committee to examine the inventions and ideas brought to it by the scientists and engineers of those days, evaluate these ideas and advise the inventors as to their value to the community and to the world. Many of those inventions have turned into the comforts, conveniences, and necessities of our technological world today.

"In 1834, the name of this committee was changed to its present form, the Committee on Science and the Arts, but its work has remained intrinsically the same.

"The Committee on Science and the Arts, with the aid of its various sub-committees, seeks out, studies and investigates the work of scientists and engineers from all over the world. These are the men whose

work has contributed most to the greater good of mankind in the physical sciences.

"When the work of a candidate has been fully and thoroughly investigated and passed upon by the Committee on Science and the Arts, his name is sent to the Board of Managers with a recommendation for award of one of the several medals of The Franklin Institute.

"The work of the Committee on Science and the Arts is long and exacting but out of that work have come the names of the very top scientists and engineers of our times. Some of them are here this evening and they are the candidates for tonight's awards.

"Ladies and Gentlemen, it is only proper and fitting that I should pay a particular tribute at this time to the members of the Committee on Science and the Arts, and compliment them on the vast store of ability and knowledge which, collectively, they represent, and upon their energy and unselfish service to The Institute and to the scientific world.

STATED MEETING

MR. LEPAGE: "Today, October 19, 1960, marks the first stated monthly meeting of The Franklin Institute of the State of Pennsylvania for this season, and the first since May 18, 1960. The Minutes of the April 20 meeting of the Institute were published in the May 1960 issue of the JOURNAL OF THE FRANKLIN INSTITUTE; the minutes of the May meeting were published in the June 1960 issue of the JOURNAL OF THE FRANKLIN INSTITUTE. If there are no corrections or additions, I declare them approved as published.

. . .

"It has been our custom for many years to take the necessary steps to welcome into membership in The Franklin Institute the Franklin Medalist of the year. At the May 1960 meeting of The Franklin Institute Dr. Roger Adams, the Franklin Medalist for 1960, was recommended and unanimously elected to Honorary Membership in The Franklin Institute, effective today. Dr. Adams, it is with great pleasure, sir, that I confer on you Honorary Membership in The Franklin Institute of the State of Pennsylvania—with all of the privileges associated with that honor. Your membership certificate and cards—and a warm welcome, a sincere welcome into this great organization."

REMARKS BY THE PRESIDENT

"In the one-hundred thirty-six years which have passed since The Franklin Institute was founded, this great institution has constantly moved with the times. Conceived as a citadel of teaching and learning in fields of mechanics and technology, as a forum for the interchange of ideas, the Institute soon became, too, an authority on engineering

standards and, as I have already indicated, a counselor to the inventor and the pioneer.

"Without relinquishing any one of these vital activities, the Institute's sphere expanded to the scientific testing of the products of engineers and engineering and then into the field of research, both basic and developmental. Our Workshops of yesteryear are become our fine Laboratories for Research and Development of today, where two or three hundred scientifically brilliant and skilled research workers continue to be responsible for some of the outstanding scientific developments of the Age. These same Workshops of which we read in our history have likewise become our distinguished Bartol Research Foundation in Swarthmore, leading the field in many spheres of basic research, in low-energy physics, in outer space radiation and in the instrumentation of some of our space satellites. Our trusteeship of The Biochemical Research Foundation in Delaware leads us into the realms of biology where vital contributions to knowledge in this field are constantly being made.

"But, vital as this research and development work is, no activity of The Franklin Institute has been or is now more important than our educational activities. Our founders and directors over this century-and-a-third of years have never deviated from the point of clear focus on this great responsibility to our Past and to the Present. Indeed, it was in the realization of this important charge that our leaders, thirty years ago, with the help of the Poor Richard Club, launched the move which resulted in the building of this great edifice with its memorial to Benjamin Franklin, its wonderful Science Museum and its outstanding Science Library.

"Today we face a new challenge, a challenge vested in the current shortage of scientifically trained personnel and the potentially greater shortage that looms ahead. It is to this latter crisis that we address ourselves now.

"President Eisenhower has made the education of children in fields of science and technology a matter of national policy and, since the seeds of interest start in pre-high school days, the challenge clearly directs us to do our part.

"Thus The Franklin Institute is again on the move, at an accelerated pace, towards specific and urgent goals set for us by national circumstances and inspired by the Institute's heritage of leadership in science education. We are about to launch upon a very substantial Museum Educational Development Program. Attendance at the Museum, already over 400,000 per year, is growing at an astounding rate; our Student Workshops, Science Fairs, special courses are beginning to overflow. We shall, therefore, increase the numbers of our courses, the personnel to handle them and the facilities available for science educa-

tion. We shall improve and expand the Museum services and provide additional teacher aids; we shall add a Junior Science Library and provide a Junior Laboratory for young people where they may perform their own experiments under able guidance. We shall introduce new Museum exhibits of Basic Science similar to the new Basic Chemistry Exhibit which some of you, no doubt, have had an opportunity to see this evening.

"All these things have been planned over the past eighteen months with care and foresight. We have had independent studies made to guide us in our judgment and we have sought and received with glowing emphasis the endorsement of educators throughout the wide area in which we serve.

"Some phases of the Plan, such as the increase in our Museum hours, have already gone into effect but the real impact of the program will be announced shortly; it will have most distinguished leadership and it is headed for unfailing and outstanding success.

"I was recently given the case history of a boy who, after years of mediocre study at schools and an aspiration to become in life but a truck driver, was one day exposed to the thrilling story of Chemistry. As the president of his college the other day told me, this boy 'caught fire,' to use his expression, and today is headed for a brilliant career as a research chemist.

"Young people are 'catching fire' constantly under the influence of The Franklin Institute and its services and within the walls of this great building."

PRESENTATION OF AWARDS

MR. LEPAGE: "One of the great contributions of The Franklin Institute has been the annual recognition of men of science. The awards of The Institute are presented, regardless of nationality, race or creed and are in recognition of unusual and meritorious work in the physical sciences. The recipient of each award for 1960 is sponsored by the Chairman of that sub-committee within the Committee on Science and the Arts which recommended him for the award. Each sponsor will present the recipient and read his citation."

Presentation of the Elliot Cresson Medals

(Founded in 1848)

This Medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

To Hugh L. Dryden, Deputy Administrator, National Aeronautics and Space Administration, Washington, D.

C.; to Arpad Ludwig Nadai, Formerly Consulting Mechanical Engineer, Westinghouse Research Laboratories, Pittsburgh, Pennsylvania; and to William Francis Gray Swann, Director Emeritus of Bartol Research Foundation of The Franklin Institute, Swarthmore, Pennsylvania.

MR. LEPAGE: "The Chair recognizes Mr. Ralph H. McClarren, Sponsor for Dr. Hugh L. Dryden."

MR. MCCLARREN: "Mr. President, I present Hugh L. Dryden for an award.

"Dr. Dryden is Deputy Administrator of the National Aeronautics and Space Administration. His professional career has been devoted mostly to the advancement and development of aviation and he has made many contributions to the basic theory of aeronautics and to the development of guided missiles. His career has been one of public service; first, with the Bureau of Standards, then with the National Advisory Committee for Aeronautics and now, with the NASA.

Hugh L. Dryden

"While at the National Bureau of Standards Dr. Dryden contributed greatly to the theory and application of wind tunnel testing and his work enabled the engineer better to interpret wind tunnel test data in order to predict realistic performance characteristics of full scale aircraft. He also made many contributions in the field of mathematics.

"During World War II, Dr. Dryden pioneered in the design, development and testing of guided missiles. In this work he developed a technique now referred to as a 'weapon system development' that required coordination of all aspects of the design integration of components as well as the development of all necessary equipment not only to construct and test but to guide the missile from the launching point to the target. The world's first automatic homing missile, called the Bat, was developed under his direction.

"I present Hugh Latimer Dryden, of Washington, D. C., as a candidate for an Elliott Cresson Medal, 'In consideration of his many scientific and practical contributions to the theory and application of aerodynamics which greatly advanced the art of wind tunnel and aircraft

design and for his guidance of and personal contributions to the design and development of the world's first automatic radar homing missile.'"

MR. LEPAGE: "Thank you, Mr. McClarren.

"Dr. Dryden, as President of The Franklin Institute of the State of Pennsylvania, I present to you this Elliott Cresson Medal and the Certificate and Report which accompany it.

"The Chair recognizes Dr. Friedrich O. Ringleb, Sponsor for Dr. Arpad Ludwig Nadai."

DR. RINGLEB: "Mr. President, I present Arpad Ludwig Nadai for an award.

"Dr. Nadai is a recognized authority in the fields of elasticity and plasticity of materials. He was born in Budapest, Hungary, studied with Professor Eugene Meyer at the Institute of Technology in Berlin and in 1911 received the degree of Doctor of Engineering. After World War I he became Professor of Applied Mechanics at the University of Goettingen (Germany). In 1927 he joined the Westinghouse Research Laboratories in Pittsburgh as a consultant mechanical engineer, which position he held until his retirement in 1949.

Arpad Ludwig Nadai

"Dr. Nadai started his scientific work with fundamental investigations on the bending of flat plates and the writing of a textbook on this subject in 1925. He became a pioneer in the field of plasticity of materials through numerous papers in scientific journals and by publication of a textbook in 1927, which remained for many years the outstanding treatment of this subject. In the same year his classical article on Plasticity in the German Handbook of Physics was printed. In 1950 the first volume of Dr. Nadai's famous book on 'Theory of Flow and Fracture of Solids' was published.

"He is the inventor of several ingenious mechanical testing devices for which he holds five patents. He is an outstanding teacher as well. For many years, he presented annual courses and, on invitation, gave lectures on Elasticity and Plasticity at universities in this country and abroad.

"I present Arpad Ludwig Nadai, of Pittsburgh, Pennsylvania, as a candidate for an Elliot Cresson Medal, 'For his pioneering work in the

field of Elasticity of materials and in Plastic Flow through many research contributions, for important educational activities, and for his authoritative treatises.'"

MR. LEPAGE: "Thank you, Dr. Ringleb.

"Dr. Nadai, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Elliott Cresson Medal and the Certificate and Report which accompany it.

"The Chair recognizes Dr. William G. Schmidt, Sponsor for Dr. William Francis Gray Swann."

DR. SCHMIDT: "Mr. President, I present William Francis Gray Swann for an award.

"Throughout a lifetime of indefatigable endeavor and of restless scientific activity, Dr. Swann has illumined many and diversified areas of human knowledge with the light of a rare intelligence. His all-encompassing mind has lingered with the imponderables of philosophy, has unraveled the complexities of relativity, has leaped into remote space on the waves of cosmic radiation.

William Francis Gray Swann

"Any attempt to miniaturize the prolific and kaleidoscopic career of such a titan would be abortive. It is, therefore, in a sense of humble inadequacy, but with inexpressible admiration, that I present William Francis Gray Swann, of Swarthmore, Pennsylvania, as a candidate for an Elliott Cresson Medal, 'For his many investigations in numerous areas of physical science and unrelated subjects that have broadened and deepened an understanding and a meaning of the universe and life therein, and more particularly for his profound and significant studies and researches in the field of cosmic radiation.'"

MR. LEPAGE: "Thank you, Dr. Schmidt.

"My great and long-time friend, it is an especial pleasure for me to present to you this Elliott Cresson Medal and the Certificate and Report which accompany it."

Dr. Swann was given a standing ovation.

Presentation of the Certificate of Merit

(Founded in 1882)

This Certificate is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

To Richard R. Moore, Chief Metallurgist, Naval Air Engineering Facility, Naval Air Material Center, Philadelphia, Pennsylvania.

MR. LEPAGE: "The Chair recognizes Mr. Francis G. Tatnall, Sponsor for Mr. Richard R. Moore."

MR. TATNALL: "Mr. President, I present Richard R. Moore for an award.

"The opening of the Aeronautic Age demanded the design and construction of structures which were light and strong, thus requiring that the designer have an accurate knowledge of the strength of materials, especially as regards their properties under repeated stress and vibration. Lack of information led to the selection of parts which frequently failed and when they did fatal accidents would occur.

Richard R. Moore

"R. R. Moore developed a rotating beam fatigue-testing machine which filled an urgent requirement for the test of a material specimen. The machine was widely accepted and permitted the standardization of testing. It was through the researches made by Mr. Moore with his machine that he was able to dispel a number of erroneous conceptions about the causes of failures in metals. On the other hand, his researches formed the basis for the publication of authoritative engineering data on the fatigue strength of numerous materials used in many types of structures.

"I present Richard R. Moore, of Drexel Hill, Pennsylvania, as a candidate for a Certificate of Merit, 'In consideration of his pioneering achievements in the field of fatigue testing of materials.'"

MR. LEPAGE: "Thank you, Mr. Tatnall.

"Mr. Moore, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you a Cetrificate of Merit and the Report which accompanies it."

Presentation of the Edward Longstreth Medals

(Founded in 1890)

This Medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes.

To W. Edward Chamberlain, Special Assistant to the Chief Medical Director for Atomic Medicine, Veterans Administration, Washington, D. C.; to John W. Coltman, Associate Director, Research Laboratory, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania; to Frederick A. Keidel, Research Project Engineer, Experimental Station, E. I. du Pont de Nemours & Company, Wilmington, Delaware; and to Moulton B. Taylor, President, Aerocar, Inc., Longview, Washington.

MR. LEPAGE: "The Chair recognizes Dr. S. Reid Warren, Jr., Sponsor for Dr. W. Edward Chamberlain."

DR. WARREN: "Mr. President, I present W. Edward Chamberlain for an award.

"Throughout his distinguished career as radiologist Dr. Chamberlain has investigated and applied the physical phenomena that underlie the use of radiation for radiological diagnosis and thereapy.

"He was one of the pioneers who developed apparatus and techniques for making X-ray movies of the thorax. He contributed important

W. Edward Chamberlain

ideas and inventions to the standardization and automatization of the processing of X-ray films. He invented fluoroscopic devices for the detection and localization of foreign bodies, and for the visualization of fractures during the process of their reduction.

"In the 1941 Carmen Lecture Dr. Chamberlain presented with care and precision the physical factors in medical fluoroscopy. He thus described the basic physical limitations of the conventional fluoroscope; in conclusion he predicted the improved results that might be achieved by using electronic means to enhance the brightness and contrast of the fluoroscopic image. Less than ten years later, successful image intensification was achieved in several laboratories.

"In spite of his busy career in medicine Dr. Chamberlain has found time to participate in public affairs; and he has an unflagging interest in helping others to learn. No one who has had the benefit of his teaching will ever forget his clarity, enthusiasm, and personal interest.

"I present W. Edward Chamberlain, of Washington, D. C., as a candidate for an Edward Longstreth Medal, 'For his continuous and effective analyses and applications of physics and engineering to the techniques of radiology; for his keen insight into all of the diverse phenomena contributing to the fluoroscopic process; and for his stimulation of the development of new devices.'"

MR. LEPAGE: "Thank you, Dr. Warren.

"Dr. Chamberlain, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Edward Longstreth Medal and the Certificate and Report which accompany it.

"The Chair recognizes Mr. Knox McIlwain, Sponsor for Dr. Frederick A. Keidel."

MR. MCILWAIN: "Mr. President, I present Frederick A. Keidel for an award.

"For many years, scientists undertaking basic research and engineers engaged in control and process studies have been confronted with the problem of measuring small water concentrations in fluid and gaseous streams.

"A new and novel instrument has been invented and developed by Dr. F. A. Keidel, of the Du Pont Company, which permits the continuous monitoring and analyzing of fluid or gaseous streams to determine the amount of water present.

Frederick A. Keidel

"The method of analysis is accomplished with a specially designed electrolysis cell in which all entering water is continuously and quantitatively absorbed and electrolyzed to hydrogen and oxygen. The indication of water content is accomplished by a measure of the electrolysis current.

"The usefulness of this new and unique instrument has had far-reaching effects in scientific and commercial applications. One of the most important and timely uses is in the detection of water present in

jet aircraft fuel in order to prevent flame-out during aircraft operations.

"I present Frederick A. Keidel, of Wilmington, Delaware, as a candidate for an Edward Longstreth Medal, 'For his development of a novel continuous electrolytic moisture analyzer, now used in large quantities throughout the country.'"

MR. LEPAGE: "Thank you, Mr. McIlwain.

"Dr. Keidel, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Edward Longstreth Medal and the Certificate and Report which accompany it.

"The Chair recognizes Dr. William H. Boghosian, Sponsor for Dr. John W. Coltman."

DR. BOGHOSIAN: "Mr. President, I present John W. Coltman for an award.

"The invention of the X-ray image amplifier marks a milestone in the use of X-ray techniques for the diagnosis of human disease. In 1941, one of the country's leading radiologists, Dr. W. Edward Chamberlain, delivered a lecture which incisively demonstrated the great medical advantages of brighter fluoroscopic images.

"A few years later through the individual researches and guidance of Dr. Coltman, the feasibility of an X-ray image brightening device was established at the Westinghouse Research Laboratories. The first laboratory model was produced in 1948. Since then, numerous articles in medical journals have revealed the great importance of this device and its widespread use in medical research and clinical practice.

John W. Coltman

"By means of a unique electron tube, the image amplifier converts a low intensity X-ray image into a pattern of electrons which are accelerated and focused to form a brightened visible image on a phosphor screen. This electronic amplification brightens X-ray images as much as 500 times thereby improving both direct and photographic examination of physiologic phenomena. At the same time, this increase in brightness permits substantial reduction in the exposure of the patient and the radiologist to X-ray radiation.

"I present John W. Coltman, of Pittsburgh, Pennsylvania, as a candidate for an Edward Longstreth Medal, 'In consideration of his

individual research contributions and of his guidance of the research program leading to the first working X-ray image-amplifier device.'"

MR. LEPAGE: "Thank you, Dr. Boghosian.

"Dr. Coltman, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Edward Longstreth Medal and the Certificate and Report which accompany it.

"The Chair recognizes Mr. Clarence B. Campbell, Sponsor for Mr. Moulton B. Taylor."

MR. CAMPBELL: "Mr. President, I present Moulton B. Taylor for an award.

"A dual purpose vehicle which could travel with equal facility on land and in the air has been contemplated since the dawn of history, as witness the aerial car of the god Jove, the flying horse of Mercury and the flying chariot of Emperor Shun. Since the first flight by man, greater attention has been given to this problem and many versions have been developed which partly solved the exacting requirements. A flying

Moulton B. Taylor

automobile has been the real dream of all experimenters in this realm of hybrid aircraft.

"No design of a flying automobile had been completely successful until Moulton B. Taylor came to the fore with his design, as all others were either a poor flying machine, or a poor road vehicle, or both. Mr. Taylor has spent many years of diligent and dedicated effort in the design, invention, development, building and testing of a completely roadable flying automobile which shows creditable performance on the road and in the air. Further, it has been certified by the Civil Aeronautics Authority for sale to the public and has been certified for operation on the highways of all states in which it has been operated.

"I present Moulton B. Taylor, of Longview, Washington, as a candidate for an Edward Longstreth Medal, 'For his conception, design, development and construction of a successful flying automobile which is completely roadable and has been fully certified for both ground and flight operation.'"

MR. LEPAGE: "Thank you, Mr. Campbell.

"Mr. Taylor, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Edward Longstreth Medal and the Certificate and Report which accompany it."

Presentation of the Howard N. Potts Medal

(Founded in 1906)

This Medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries, inventions or products of superior excellence or utilizing important principles.

To Charles Stark Draper, Professor and Head of Department of Aeronautics and Astronautics, Director of Instrumentation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.

MR. LEPAGE: "The Chair recognizes Mr. Edward L. Forstall, Sponsor for Dr. Charles Stark Draper."

MR. FORSTALL: "Mr. President, I present Charles Stark Draper for an award.

"When a submarine travels submerged for a considerable period of time, it is essential that the navigator be continuously aware of his location if he is to reach his intended destination. Celestial navigation is not possible when submerged; and guidance by external electronic means is subject to jamming by an enemy, is not feasible beyond a limited depth, and requires a world-wide chain of transmitting stations.

Charles Stark Draper

"When an intercontinental missile is in flight it must be constantly guided if it is to reach the precise spot at which it was aimed. Here, again, external means of guidance are subject to severe limitations.

"When a man-made satellite is to be placed in orbit about the earth or a machine directed through space to the moon or a distant planet, there are rigid mathematical requirements for a navigation system that is not dependent on electronic means.

"The solution of all these guidance problems has been found to be an internal guidance system known as Inertial Navigation. Without this system our long-distance missiles would be ineffective and the navigation of a submarine while continuously submerged for days or weeks would not be feasible. The accurate aiming and guidance of a Polaris Missile from a submerged submarine requires the application

of inertial guidance to both. Inertial guidance is also essential to the precise placement of satellites in orbit and for distant flights into space.

"The heart of this system is a gyroscope of unbelievable accuracy due to the amazing nicety of its design and construction and to the ingenious mechanisms which continuously correct deviations from the desired path.

"The practicability of this inertial guidance system—so vital to our nation's defenses and its scientific progress—is due in large measure to the pioneering efforts of Dr. Draper in the conception, the development and the testing of equipment which met the rigid specifications that he himself had formulated.

"I present Charles Stark Draper, of Cambridge, Massachusetts, as a candidate for a Howard N. Potts Medal, 'In consideration of his substantial and significant contributions to the science of inertial navigation, which have resulted in outstanding advances in the accuracy of navigation below and on the surface of the ocean, through the air and into space.'"

MR. LEPAGE: "Thank you, Mr. Forstall.

"Dr. Draper, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you a Howard N. Potts Medal and the Certificate and Report which accompany it."

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Presentation of the Louis E. Levy Medals

(Founded in 1923)

This Medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, *preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.*

To Ezra S. Krendel, Manager, Engineering Psychology Laboratory, The Franklin Institute Laboratories for Research and Development, Philadelphia, Pennsylvania; and Duane T. McRuer, President, Systems Technology, Inc., Inglewood, California.

MR. LEPAGE: "The Chair recognizes Professor George W. Patterson, 3rd, Sponsor for Mr. Ezra S. Krendel and Mr. Duane T. McRuer."

PROFESSOR PATTERSON: "Mr. President, I present Ezra S. Krendel and Duane T. McRuer for awards.

"Their paper, 'The Human Operator as a Servo System Element,' presents results of fundamental theoretical and experimental researches into man-machine relationships in automatic control systems. The increasingly wide use of closed-loop feedback control systems, such as are found in automatic pilots and inertial navigation guidance systems is one of the marvels of modern technology. But there exists another important class of control systems, those that utilize a human being

as an operator. For example, an aircraft pilot pursuing a maneuvering objective, an operator tracking a moving target, constitute a man-machine control system, with the feedback link in the human nervous

Ezra S. Krendel

Duane T. McRuer

system. In order to improve the design techniques for the mechanical portion of the system, a quantitative description of the relevant human psychodynamics is required. Man is notably nonlinear, his characteristics vary with training, and thus the classical Laplace-transform no longer applies: McRuer and Krendel have developed in their paper, a quasi-linear descriptive function, and this leads to a generalization of the linear analysis that can be applied to the man-machine system.

"This descriptive function is obtained by tracking-task experiments on a group of subjects, utilizing noise-like inputs. The authors have taken data from their own experiments, as well as from those of others, and have developed a family of descriptive functions that are related to system dynamics and other relevant parameters. These provide the quantitative data that the designer of man-machine systems needs to apply to his problems.

"I present Duane T. McRuer, of Inglewood, California, and Ezra S. Krendel, of Swarthmore, Pennsylvania, as candidates each for a Louis E. Levy Medal, 'In recognition of their outstanding paper, "The Human Operator as a Servo System Element," appearing in the May and June, 1959, issues of the JOURNAL OF THE FRANKLIN INSTITUTE.'"

MR. LEPAGE: "Thank you, Professor Patterson.

"On behalf of The Franklin Institute of the State of Pennsylvania, I present to you, Mr. Krendel, and to you, Mr. McRuer, each a Louis E. Levy Medal and the Certificates and Reports which accompany them.

Presentation of the George R. Henderson Medal

(Founded in 1924)

This Medal is awarded for meritorious inventions or discoveries in the field of Railway Engineering.

To Ernest Chatterton, Engineering Consultant, Formerly Chief Engineer, D. Napier and Son, Limited, London,

England; and Herbert Sammons, Managing Director, D. Napier and Son, Limited, London, England.

MR. LEPAGE: "The Chair recognizes Mr. R. Thomas Sawyer, Sponsor for Mr. Ernest Chatterton and Mr. Herbert Sammons."

MR. SAWYER: "Mr. President, I present, *in absentia*, Herbert Sammons and Ernest Chatterton for awards.

"Mr. Herbert Sammons, the Managing Director of D. Napier and Son, of London, England, conceived the basic idea and designed the Diesel engine built in the form of a delta. In this arrangement the crankshafts are located at the apex of each angle of an equilateral triangle and operate pistons that oppose each other in each cylinder. There can be eighteen or more cylinders. The first patent was issued in 1951 to Mr. Sammons.

Ernest Chatterton

Herbert Sammons

"Mr. Ernest Chatterton, until his retirement last year, was the Chief Engineer, Piston Engine Division of D. Napier and Son, and is responsible for the development of the Deltic Diesel Engine as a practical and useful power plant for many applications, including the Deltic Diesel Locomotive.

"The triangular arrangement of cylinders with opposed piston assemblies and the unique exhaust turbosupercharger system have so condensed the assembly as to give a high power-to-weight ratio, which is particularly suitable for locomotive application. This has resulted in a weight of 6 pounds per horsepower for the 1650 horsepower unit as compared with 15 to 20 pounds per horsepower for conventional two-cycle and four-cycle locomotive Diesel engines.

"The Deltic road locomotive of 3300 horsepower holds the world's record as being the most powerful single power unit and with the lightest power-to-weight ratio.

"I present, *in absentia*, Herbert Sammons, of London, England, and Ernest Chatterton, of Ruislip, Middlesex, England, as candidates each for the George R. Henderson Medal, 'In consideration of their outstanding achievements, the invention, design and development of the "Deltic" Diesel-electric drive for railway locomotives.'"

MR. LEPAGE: "Thank you, Mr. Sawyer.

"I call upon Mr. E. S. Dean, good friend of our Medalist, Mr. Herbert Sammons. Mr. Dean, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you for Mr. Sammons this George R. Henderson Medal and the Certificate and Report which accompany it. I know that you will see that he receives it with our warm well wishes.

"I call upon the Honorable Geoffrey Aldington, Consul General in Philadelphia for Her Majesty Queen Elizabeth II.

"Mr. Aldington, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you, for Ernest Chatterton, this George R. Henderson Medal and the Certificate and Report which accompany it. I know that you will see that our honored Medalist receives it with our sincere well wishes."

Presentation of the John Price Wetherill Medals

(Founded in 1925)

This Medal is awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known.

To Raymond Castaing, Staff Member, Laboratoire de Physique des Solides, Université de Paris, France; to Walter Juda, Executive Vice President and Technical Director, Ionics, Incorporated, Cambridge, Massachusetts; and to Victor Vacquier, Research Geophysicist, Scripps Institute of Oceanography, University of California, La Jolla, California.

MR. LEPAGE: "The Chair recognizes Mr. John H. Neher, Sponsor for Dr. Raymond Castaing."

MR. NEHER: "Mr. President, I present, *in absentia*, Raymond Bernard Castaing for an award.

Raymond Castaing

"A chemist, making an analysis, must proceed on the assumption that the components of the sample are uniformly distributed. The metallurgist, on the other hand, knows or suspects that the distribution of the components is not uniform, and is vitally interested in how they are distributed.

"Methods heretofore available for the study of metals on a microscopic scale have been for the most part, directed at structure. The optical microscope is capable of magnification of a few thousand diameters. The electron microscope extends this tenfold but permits no better evaluation of the composition.

"Heretofore the spectroscope has been the only instrument available for chemical analysis of very small quantities, and it requires a microgram of material of which it is capable of finding an average analysis, but no structural information.

"By an ingenious combination of an electron microscope and a spectrograph arranged to measure in addition the Bragg X-ray angles, Dr. Castaing has developed an instrument which indicates not only the structure but also the chemical composition of an extremely small sample.

"I present, *in absentia*, Raymond Bernard Castaing, of Paris, France, as a candidate for a John Price Wetherill Medal, 'In consideration of his development of the electron probe microanalyzer, which has made possible the metallurgical analysis of a sample, not only as to structure, but also quantitatively the chemical analysis of its structural components down to particles of one micron in diameter.'"

MR. LEPAGE: "Thank you, Mr. Neher.

"In the absence of Dr. Castaing, the Chair recognizes M. Pierre Gabard, Consul in Philadelphia for the Republic of France.

"On behalf of The Franklin Institute of the State of Pennsylvania, in the absence of Dr. Raymond Bernard Castaing, I present to you, Mr. Gabard, this John Price Wetherill Medal and the Certificate and Report which accompany it. Will you see that Dr. Castaing receives it in good order?

"The Chair recognizes Mr. Charles M. Cooper, Sponsor for Dr. Walter Juda."

MR. COOPER: "Mr. President, I present Walter Juda for an award.

Walter Juda

"The high rate of growth in the world's population, almost of explosive dimensions, has placed special emphasis on the conservation of fresh water and its production. There are limitations to its acquirement from wells and dams on streams and rivers; therefore other sources

must be discovered to take care of immediate demands of arid regions as well as the crucial demands of the future.

"Walter Juda has made an outstanding contribution to this vital requirement of mankind through the invention and development of a technique for desalting brackish waters somewhat less salty than sea water. His method of removing salt and minerals by the use of insoluble, infusible synthetic organic resin membranes in the filtering process has been commercially feasible and practical. The resin functions as an ion exchange agent and has ionic groups combined with it.

"I present Walter Juda, of Cambridge, Massachusetts, as a candidate for a John Price Wetherill Medal, 'For his development of a commercial method of desalting saline water by electrodialysis.'"

MR. LEPAGE: "Thank you, Mr. Cooper.

"Dr. Juda, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you a John Price Wetherill Medal and the Certificate and Report which accompany it."

"The Chair recognizes Mr. Lee Powers Hynes, Sponsor for Mr. Victor Vacquier."

MR. HYNES: "Mr. President, I present, *in absentia*, Victor Vacquier for an award.

Victor Vacquier

"While working with the Gulf Research and Development Company, in 1941, Mr. Vacquier discovered an arrangement of electromagnetic circuits which had sufficient sensitivity and stability to operate successfully the first practical airborne magnetometer. This is an instrument to measure the intensity of the earth's magnetic field at any point and the variations in this field.

"In June 1941 the Navy flew this magnetometer in a plane and successfully detected a submarine. This provided a much needed tool for combating enemy undersea craft. In July 1941 Vacquier applied for a patent which was granted September 3, 1946.

"After the war, magnetometers became widely used for aerial reconnaissance to locate mineral and oil deposits. One company owns fifteen instruments and has flown surveys of two million square miles. One of their important discoveries was the magnetite deposit near

Morgantown, Pennsylvania, which is being worked by the Bethlehem Steel Company.

"The United States Geological Survey has flown more than a million miles of traverses for use in making aeromagnetic maps. The airborne magnetometer has become one of the most useful tools for geophysical investigations, replacing the slow cumbersome work by ground crews, which in the past could only make spot checks at selected locations.

"I present, *in absentia*, Victor Vacquier, of La Jolla, California, as a candidate for a John Price Wetherill Medal, 'In recognition of his important invention of the sensitive saturating core magnetometer element, and his development of the first practical airborne magnetometer, providing the fundamental principles which are basic to the later developments.'"

MR. LEPAGE: "Thank you, Mr. Hynes.

"I call upon Mr. Frederick Braddon. On behalf of The Franklin Institute of the State of Pennsylvania, I present to you, Mr. Frederick Braddon, in the absence of Mr. Vacquier, this John Price Wetherill Medal and the Certificate and Report which accompany it. Will you see that Mr. Vacquier receives it in good order?"

Presentation of the Walton Clark Medals

(Founded in 1926)

This Medal is awarded to the "author of the most notable advance in knowledge or improvement in apparatus, or in method concerning the science or the art of gas manufacture or distribution of utilization in the production of illumination, or of heat, or of power."

To Robert W. Cook, Vice President, C. W. Fuelling, Inc., Decatur, Indiana; and Lee F. McBride, C. W. Fuelling, Inc., Decatur, Indiana.

MR. LEPAGE: "The Chair recognizes Mr. Joseph Gray Jackson, Sponsor for Mr. Robert W. Cook and Mr. Lee F. McBride."

MR. JACKSON: "Mr. President, I present Robert W. Cook and Lee F. McBride for awards.

"The leakage from gas mains poses serious problems to public safety as well as incurring heavy repair costs and torn-up thoroughfares. Some leakage can be attributed to small movements and shifts in the earth

Robert W. Cook

Lee F. McBride

which place strains on the joints; however, the main cause stems from dried out jute joint packing. Manufactured gas is moist and tends to expand the packing but natural gas is almost anhydrous thus becoming a drying agent. Since natural gas is used for the most part in many areas of the country, an effective method of sealing leaking joints became an urgent necessity.

"Mr. Cook and Mr. McBride developed an extremely effective process and the equipment for sealing the joints from inside of mains from 8 to 24 inches in diameter and in sections 600 feet long. A sensing device locates each joint, cleans it and applies the Thiokol base sealer.

"The sealing equipment developed by Messrs. Cook and McBride is known as the Fuelling Method and has been so effective that in the sealing of 1500 joints in the Philadelphia area only several leaks of indeterminate origin subsequently were found.

"I present Robert W. Cook and Lee F. McBride, of Decatur, Indiana, as candidates each for a Walton Clark Medal, 'For their contribution to public welfare and safety by the development of a successful leak-sealing system for gas mains.'"

MR. LEPAGE: "Thank you, Mr. Jackson.

"On behalf of The Franklin Institute of the State of Pennsylvania, I present to you, Mr. Cook, and to you, Mr. McBride, these Walton Clark Medals and the Certificates and Reports which accompany them.

Presentation of the Frank P. Brown Medal

(Founded in 1938)

This Medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

To R. Buckminster Fuller, Structural Designer, Forrest Hills, New York.

MR. LEPAGE: "The Chair recognizes Mr. Walter J. Kinderman, Sponsor for Mr. R. Buckminster Fuller."

MR. KINDERMAN: "Mr. President, I present Richard Buckminster Fuller for an award.

"Shelter cover has always been one of man's most basic and pressing needs. It is particularly appropriate, therefore, that great present day advances in this primary need of mankind be recognized.

"The geodesic dome is such a modern advance and represents a radical departure from the more conventional shelter structures with phenomenal gains in strength, weight, efficiency, flexibility for size, freedom from interior supports and a simple beauty of a spherical shell component form made up of covered lattice cell structure typical of the microarchitecture of crystal substances. Geodesic domes have replaced housing from tents to airdromes in the Services, are withstanding

hurricane gales along the Arctic DEW Line, serving as auditoriums and exhibit halls, and as cover for huge industrial operations. Size is no limitation and a huge transparent geodesic dome large enough to shelter the heart of Manhattan is considered feasible.

"The United States Marine Corps hailed their geodesic dome adaptation ' . . . as the first basic improvement in mobile military shelter in 2600 years . . . .' Mr. Khrushchev was sufficiently impressed by the huge gold tinted geodesic dome sheltering the American National Exhibition at Sokoniki Park at the recent Moscow Fair that he prevailed on our State Department to have the inventor lecture on his work under the roof of his own creative imagination.

R. Buckminster Fuller

"I present Richard Buckminster Fuller, of Forest Hills, New York, as a candidate for the Frank P. Brown Medal, 'In consideration of his inventive conception of the Geodesic Domes, the development of the associated mathematical derivations and the resolution of the theoretical principles to practice as a vastly more efficient and economic means of providing full-span shelter cover against the elements, without need for interior supports.'"

MR. LEPAGE: "Thank you, Mr. Kinderman.

"Mr. Fuller, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you the Frank P. Brown Medal and the Certificate and Report which accompany it."

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Presentation of the Stuart Ballantine Medals

(Founded in 1946)

This Medal is to be awarded in recognition of outstanding achievement in the fields of Communication and Reconnaissance which employ electromagnetic radiation.

To Rudolf Kompfner, Director of Electronics and Radio Research, Bell Telephone Laboratories, Inc., Holmdel, New Jersey; and John R. Pierce, Director of Research—Communications Principles, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey; and to Harry Nyquist, Formerly Assistant Director of Systems Studies, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.

MR. LEPAGE: "The Chair recognizes Mr. C. Raymond Kraus, Sponsor for Dr. Rudolf Kompfner and Dr. John R. Pierce."

MR. KRAUS: "Mr. President, I present Rudolf Kompfner and John R. Pierce for awards.

"In the summer of 1941, Rudolf Kompfner, a Vienna-born professional architect whose consuming hobby was science and electronics, joined the British Admiralty service in the Physics Department at Birmingham University.

"Britain was then at war, and it was the goal of the scientists with whom Dr. Kompfner was associated to develop electron tubes which would materially improve the performance of radar. It was while working on a klystron amplifier that Dr. Kompfner realized that such a device had a fundamental weakness which limited its sensitivity and

Rudolf Kompfner

John R. Pierce

hence the range of radar. This weakness stemmed from the fact that the radio-frequency field which interacted with the electron beam was stationary. He conceived the idea of making the radio-frequency field travel in synchronism with the electron beam, and thus overcome the weakness inherent in the klystron. To this end, he constructed a helical wave propagation circuit and directed an electron beam along its axis with the result that a radio-frequency signal applied to the helix appeared in amplified form at the other end of the helix. Tests showed that this 'traveling wave tube' not only had greater sensitivity than the best klystron then known, but also that its operating bandwidth exceeded the limits of the available test equipment—sixty megacycles.

"Dr. J. R. Pierce, of Bell Telephone Laboratories, learned of Dr. Kompfner's achievements and became greatly interested in the new tube. He appreciated the great bandwidth potential of the device and foresaw its significance in the field of microwave communications. His analysis of the device led to his classical theory of traveling wave tube operation.

"This was made available in his books, 'Theory and Design of Electron Beams' and 'Traveling Wave Tubes,' which are still the authoritative works in the field. Using his theory, Dr. Pierce conceived of the great benefits to be derived from inserting loss in the wave propagation circuit, thereby insuring the stability of the traveling wave tube.

"In 1951, Dr. Kompfner joined Dr. Pierce at the Bell Telephone Laboratories. Since that time they have been among the leading scientists contributing to the advancement of traveling wave tube technology. Their creativeness is evidenced by Dr. Kompfner's thirty-odd and Dr. Pierce's seventy-odd patents and patent applications.

"Today the traveling wave tube is one of the most valuable instruments in the fields of microwave communications, radar, and guided missile control.

"I present Rudolf Kompfner, of Far Hills, New Jersey, and John R. Pierce, of Berkeley Heights, New Jersey, as candidates each for a Stuart Ballantine Medal, 'For the conception and invention of the traveling wave tube amplifier, a device based on a new principle of continuous interaction between an electromagnetic wave and an electron beam, that removes the frequency bandwidth limitation of electronic tubes; for the formulation of the fundamental theory of its operation and for its development as an important instrumentality in commercial and military communications.'"

MR. LEPAGE: "Thank you, Mr. Kraus.

"Dr. Kompfner and Dr. Pierce, on behalf of The Franklin Institute of the State of Pennsylvania, I present to each of you a Stuart Ballantine Medal and the Certificate and Report which accompany them."

"The Chair recognizes Mr. William E. Bradley, Sponsor for Dr. Harry Nyquist."

MR. BRADLEY: "Mr. President, I present Harry Nyquist for an award.

"There is hardly any other living man who has made such significant contributions to the art of communication electronics, and it is especially interesting that some of these were published by him a decade or so prior to their widespread utilization.

Harry Nyquist

"Communications scientists are especially grateful to Dr. Nyquist for three major contributions. He clearly set forth the principles which govern the rate of transmission of information through systems having limited frequency bandwidth; he explained the theoretical basis of thermal noise in electric circuits, predicting quantitatively the magni-

tude of such noise; and he derived an extremely useful and theoretically elegant method to determine the stability of feedback amplifiers or servo systems. These three contributions are so fundamental that it is difficult to imagine any modern electronics communication or control system which is not based upon at least two of them.

"I present Harry Nyquist, of Millburn, New Jersey, as a candidate for a Stuart Ballantine Medal, 'For his theoretical analyses and practical inventions in the field of communications systems during the past forty years including, particularly, his original work in the theories of telegraph transmission, thermal noise in electric conductors, and in the theory of feedback systems.'"

MR. LEPAGE: "Thank you, Mr. Bradley.

"Dr. Nyquist, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you a Stuart Ballantine Medal and the Certificate and Report which accompany it."

Presentation of the Franklin Medal

(Founded in 1914)

This Medal is awarded annually to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

To Roger Adams, Research Professor of Chemistry, Emeritus, University of Illinois, Urbana, Illinois.

MR. LEPAGE: "The Chair recognizes Dr. Harvey A. Neville, Sponsor for Dr. Roger Adams."

DR. NEVILLE: "Mr. President, I have the honor to present to you the distinguished chemist, Roger Adams, as a candidate for the highest award of The Franklin Institute.

"Dr. Adams was born in Boston, Massachusetts, and was educated at Harvard University which awarded him the A.B., A.M., and Ph.D. degrees. After a year of post-doctoral study in Germany he returned to Harvard as an instructor and three years later, in 1916, joined the faculty of the University of Illinios where he has served continuously since that date. He was Head of the Department of Chemistry and Chemical Engineering from 1926 to 1954 and was then appointed Research Professor. Although retired as Professor Emeritus in 1957, Dr. Adams is still actively engaged in writing, in serving on national scientific boards, and in the direction of research.

"Roger Adams has contributed more than four hundred articles to the scientific literature of organic chemistry and is the author or editor of numerous treatises which are the standard reference books of all organic chemists. The highest honors and offices at the disposition of American chemists have been bestowed upon him, and he has also been

awarded the Davy Medal by the Royal Society of London and the A. W. Hofmann Medal by the German Chemical Society. He has been elected an Honorary Member or Honorary Fellow by the chemical societies of eight foreign countries and has been the recipient of numerous honorary degrees.

"Dr. Adams has served the government of the United States as a scientific advisor on many commissions and boards here and in foreign countries. He has served on the President's Scientific Advisory Board and is a member of the Board of Directors of the National Science Foundation. The Roger Adams Medal was established in his honor last year, to be awarded biennially at the Organic Chemistry Symposium.

"It would not be appropriate or feasible here to discuss or even to list the subjects of the various scientific investigations conducted by Roger Adams. Brief mention of a few will illustrate the breadth, variety, and importance of his work in organic chemistry.

Roger Adams

"Of greatest significance is his discovery of the platinum oxide hydrogenation catalyst and his invention of the low-pressure catalytic hydrogenation apparatus. This method has had a profound influence upon the development of all branches of organic chemistry, enabling organic chemists and biochemists to extend their studies into many new areas.

"The earliest and most extensive systematic investigation of steric strain in organic molecules was initiated by Dr. Adams through a study of restricted rotation around the carbon-carbon single bond. This work has provided a method of measuring the effective steric size of various functional groups and for determining the mechanism of certain organic chemical reactions.

"Dr. Adams has devoted much attention to the chemistry of synthetic drugs and of natural products having pharmacological action. In this area are his comprehensive studies of structure and synthesis of an important group of alkaloids. These studies have elucidated the botanical-chemical relationships of this family of drugs.

"Finally, perhaps the most important contribution of Professor Adams has been in his role, for more than forty years, as a great teacher

—a brilliant and effective lecturer in the classroom, a stimulating and wise leader in the research laboratory. It is very probable that more doctorates in organic chemistry have been earned under his guidance than can be attributed to any other teacher of chemistry, and many of these former students have now attained high distinction through their own accomplishments.

"Therefore, Mr. President, with this formal citation: 'In recognition of his many contributions to the science of organic chemistry, particularly his widely useful method of catalytic hydrogenation, his comprehensive investigation of alkaloids, and his systematic studies of molecular structure; and because of his eminent achievements as a teacher, as an author and editor, and as a leader in the professional organizations of science,' I present to you Roger Adams, of Urbana, Illinois, as a candidate for The Franklin Medal."

MR. LEPAGE: "Thank you, Dr. Neville."

MR. LEPAGE: "Dr. Adams, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you The Franklin Medal and the Certificate and Report which accompany it.

"Three years ago we began giving serious consideration to a new Chemistry Exhibit in the great Science Museum of The Franklin Institute. The planning, the acquisition of the necessary funds and the actual building of the exhibit have filled the time between then and now.

"During this same period, the Committee on Science and the Arts, ever seeking the distinguished candidates for our medal awards, began studying the work of Dr. Roger Adams. It is by sheer coincidence that the unveiling of the new Chemistry Exhibit and the naming of a great and world renowned chemist for the Franklin Medal should each come to a common focus at this time. This then might be considered the month of Chemistry for The Franklin Institute.

"I don't believe it necessary for me further to introduce Dr. Adams. You have all, in this room, met him personally; you have heard of his accomplishments from his sponsor, Dr. Neville; we have just presented him The Franklin Medal for 1960. Dr. Adams, I am deeply honored to call upon you for the address of the evening."

Mr. LePage then introduced Dr. Adams as the speaker of the evening.

ADDRESS BY ROGER ADAMS

(See page 520 of this JOURNAL for the text of Dr. Adams' address.)

After Dr. Adams had delivered his talk, Mr. LePage conveyed to him the thanks of the Institute, dismissed the assembly with a cordial word and declared the meeting adjourned.

ORGANIC CHEMISTRY IN THE SPACE AGE*

BY

ROGER ADAMS[1]

Mr. President, Fellow Medalists, Ladies and Gentlemen: It is with much appreciation that I receive the Franklin Medal. It is indeed a rare privilege to have one's name associated with those of such distinguished scientists and technologists who are past medalists, and especially for me, with the names of two organic chemists, Paul Sabatier of France and Sir Robert Robinson of England.

For almost a century organic chemistry has been a glamorous field of science. It has contributed much to related disciplines such as botany, zoology, physiology and bacteriology. It has been the basis of a host of our everyday consumer items, what we buy to make the world a happier place to live in.

In a newspaper advertisement which appeared last year, the heading reads "duPont's discoveries on exhibit at Macy's" and it states "The store is overflowing with items from films that seal frozen foods to washable upholstery fabrics; from eyeglass frames to rich, sturdy yarns in rugs, draperies and tablecloths; from tough, safe toys to nylon dog bones and Lucite fish tanks; from spray-on paint to perfume powered by duPont aerosols. In the world of fashion, wash and wear fabrics make life easier, and summer will be cooler for suits and dresses of Dacron."

And in a news item on the same page of the newspaper the last paragraph reads, "On a special survey of its merchandise, Macy's reported it was 'astounded to learn' that it uses duPont products in 172 of its 177 selling departments. What are the five where they aren't used? Pianos (the keys are really ivory); unpainted furniture; ceramics imported from Italy; sewing machines from Japan, and imported Oriental rugs."

The scope of organic chemistry has been so broad and new items of commerce accepted with such nonchalance that neither the public nor the embryo scientist appreciates the skill, effort, and scientific acumen of those responsible for the products.

During the last fifteen years, new areas of science have overshadowed organic chemistry through fantastic discoveries that have excited widespread attention: the A-bomb, H-bomb, proximity fuses, radar controls, automation, and application of atomic energy to industrial uses. News

* Delivered at the 1960 Medal Day Meeting of The Franklin Institute, October 19, 1960, in acceptance of the Franklin Medal.

[1] Research Professor of Chemistry, Emeritus, University of Illinois, Urbana, Illinois.

items about reactors, accelerators, transistors, computers, jets, missiles, satellites, and most recently the "tunnel diode," the spectacular advance in the field of electronics, have filled the public press. Industry has devoted many many millions and the government literally billions of dollars to these fields of science and technology. The International Geophysical year was an outstanding success. And now oceanography, radio-astronomy, atmospheric science are demanding their share of government support.

It is not surprising that many young scientists, who might have specialized in organic chemistry, have turned to physics, electrical engineering, electronics, geophysics and related subjects and that a serious shortage of organic chemists has resulted.

In articles on military and space rockets and missiles, the organic chemist is never mentioned. The public is left with the impression that such items are a complex assemblage of mechanical and electronic devices that are synchronized adequately to give results. They are rarely informed of the role of the organic chemist in these developments.

Propellants, either liquid or solid, are required for jet systems. Liquid propellants present problems in storage and handling. The organic chemist has now furnished a liquid propellant of excellent properties, dimethylhydrazine. It is more easily pumped and utilized in jet systems and with a proper oxidizing agent provides a fuel superior to that derived from the previously used hydrazine.

But solid propellants are likely in most instances to replace liquid propellants. In this field the organic chemist has made an important contribution. Solid propellants usually consist of three components, an oxidizer such as ammonium perchlorate, a metal in powdered form for providing stability and increased energy, and a binder that at the same time is a part of the reducing system. The success of the propellant in large measure depends upon the binding agent: it must have precisely the right properties, adherence to the grains and to the rocket case so that burning will be even and not occur between the grain and the case; it must have the right coefficient of expansion since the shell case and grains of propellant are quite different in this respect and considerable strain may occur during wide temperature changes. The effective binders, organic chemicals somewhat elastic in character, have resulted from the researches of the organic chemist.

The electronic systems used in guidance and recording equipment of rockets and satellites require tape-recorders. Information is recorded on the tape and relayed to the earth at the proper time. The mylar-tape film, an organic chemical product, is much superior to other kinds because it functions satisfactorily during wide variations in temperature.

Gyro stabilizers are utilized to control the direction and accuracy of the flight of a rocket. The rotating portion of the gyroscope is usually suspended in an organic liquid of very special composition, a fluorocarbon.

But let us turn to contributions of the organic chemist that are of more general interest. There has been a spectacular development in the field of synthetic polymers, those complex giant molecules formed by the chemical reaction of many simple ones. Forty-five years ago bakelite was the only commercial polymer. Its use in phonograph records and cheap articles of commerce was well-known. In the 30's polymethyl methacrylate was discovered, that beautifully transparent material known commonly as Lucite or Plexiglas. Its production during the war expanded enormously because of its use in bomb bays to take advantage of its light weight and non-shatterability. Glyptals from glycerol and phthalic anhydride were developed in the same period and became valuable bases for paints. But the outstanding discovery and development was nylon, used for easily washed and rapidly drying fabrics. This polyamide was the first synthetic fiber and was so generally accepted that search for other synthetic fibers developed as a broad field of research.

With this background, post-war investigation of all types of polymers became one of major effort in organic chemistry. Polymers can be made with all sorts of properties. By modifying quantities of two components to be copolymerized or by the addition of a third component and by utilizing varying conditions for polymerization, it is possible literally to obtain an infinite number of combinations which give products each with different properties.

A careful study of the theoretical aspects of polymer chemistry was started in the 30's and has been intensified since then. Not yet, however, is the organic chemist able to predict in more than qualitative fashion the properties of the product prepared from any particular components under a fixed set of conditions. In spite of this short-coming, polymers have been synthesized that are stronger than steel, tougher than any plant fibers, more transparent than glass, more chemically resistant than most metals, more stable to heat than any natural organic products.

In the post-war years the acrylic type fiber which utilizes as a base acrylonitrile was discovered. Six products of this kind each a bit different from the other, known to the trade as Orlon Acrilan, Creslan, Dynel, Verel, and Zefran, are now marketed primarily as substitutes for wool. Polyester type fibers came next, represented first by the trade product Dacron and later by Kodel for use, sometimes blended with with wool, in crease-resistant fabrics, and for rain-proof materials. Other fibers for special applications have also been synthesized and marketed.

The term "plastic" is most suitably used to represent those polymers which can be injected or compression molded. Plastics have had a fantastic growth and acceptance. The most important of these is polyethylene, readily synthesized from ethylene obtained by cracking of

natural gas or petroleum. There are two kinds of polyethylene, the first of lower density and the second of higher density. The lower density product is by far the more important and at present is the leading film material, more than 70% of which is used in the packaging industry for grocery products and for almost every kind of article of commerce, including pianos.

A polymer of a similar type, polypropylene, has recently emerged as a product of great promise. It will probably displace the less important higher density polyethylene because of its superior properties. Made from readily available propylene, polypropylene has a high softening point, a toughness under service conditions, and an ease of molding into products having lustrous surfaces. It can be made into a film that is stiffer than low-density polyethylene and less brittle and less impervious to moisture than cellophane. It should replace cellophane and other cheap plastics and will find application in house and hospital wares, automotive parts, in extruded products such as fiber for rope, textiles and upholstery and in pipe for hot and cold water. Plant capacity for production of the three polymers just described will exceed one billion pounds next year.

Another class of polymers is called elastomers which, as the name indicates, are polymers with elastic properties. Of the new developments under way in this country one that may result eventually in world-wide impact is the new cis-polyisoprene rubber that is identical with natural rubber. The so-called synthetic rubber (butadiene-styrene copolymer) now in common use differs from natural rubber in several physical and chemical properties. This synthetic rubber is quite satisfactory for automobile tires although somewhat inferior to the natural in adhesion to fabric. It fails however for truck tires because of its tendency to degrade rapidly at the high temperature developed from road friction caused by heavy truck loads. Therefore natural rubber has been utilized almost exclusively for truck tires.

The basic information for the synthesis of cis-polyisoprene has been acquired. Cheap isoprene is available from the distillate of appropriately cracked petroleum products or even by synthesis. The synthetic cis-polyisoprene rubber has the one disadvantage of being too pure; contamination with impurities is required in order for the properties to match exactly those of natural rubber. Although a plant with capacity for 20 million pounds annually has already been constructed and another much larger is on the drawing board, it will require years to completely perfect the operations in order to attain minimum costs and to build industrial plants adequate to supply hundreds of millions of pounds.

cis-Polybutadiene, made by a similar process, gives promise of being very important commercially, for it has very similar properties to natural rubber and indeed even a higher resilience and lower hysteresis

than natural rubber so that it will stand up better under severe service conditions. A ball of cis-polybutadiene will bounce considerably higher under the same force than a ball of natural rubber. The only drawback to cis-polybutadiene rubber at present is the necessity of designing new equipment for its processing. However, it has been discovered that a blend of 50% natural rubber and 50% cis-polybutadiene can be processed on available machinery. And it has been demonstrated that truck tires made from the product perform with high satisfaction.

As of today the ratio of synthetic to natural rubber used in commerce is about 55:45. The total amount of rubber consumed has risen to such a level that the present rubber plantations cannot supply their 45 per cent. Immediate expansion of plantations is being undertaken in many parts of the world as I witnessed in New Guinea a few weeks ago where each of two 3,000 acre plantations were expanding by 2,000 acres. Of the total cost of natural rubber more than half is for labor, and since the laborers receive low wages any substantial reduction in cost of natural rubber in the future seems very unlikely. I can foresee only that within a decade these plantations will be essentially abandoned and natural rubber will follow the pathway of natural indigo some sixty years ago. It will be replaced by synthetic products.

The polymer field is represented broadly by dozens of different types of products which have found application in most every field of commerce, such as adhesives, protective and decorative coatings, piping, stoneware and metal replacements, optical lenses, insulation, tough and abrasive-resistant products. Over 5 billion pounds of polymers, including plastics and elastomers, are being produced annually and in dollar value these represent more than half of the dollar business of the total chemical industry.

The organic chemist has always been a major factor in the discovery and development of new and useful drugs. Such drugs are discovered only by the efforts of a team of scientists, a team of at least three, the organic chemist, the pharmacologist and the clinician. But depending on the character of the disease to be treated, the services of other scientists may be necessary, such as the bacteriologist or the virologist.

No individual can escape indefinitely the ravages of disease. The organic chemist has contributed much to medicine and in his search for new remedies is engaged in a highly humanitarian program. Success during the past two decades has been unusual. In that period he has contributed his share to the development of the sulfur drugs, antibiotics, antihistaminics, cortisone and related compounds, oral antidiabetic agents, tranquilizers, psychic energizers, drugs for mental diseases, diuretics and medicinals to control high blood pressure. There are still many diseases for which better drugs are needed and many for which no remedy has been found. Of these latter, cancer has caused more anxiety and deaths than any of the others. More money and effort are being

directed to this problem than to any other medical problem. The public, the foundations, industrial companies, and the government are contributing large sums for research on all phases of this subject.

Politicians, in view of the phenomenal success in development of the A-bomb, often assume that any large problem such as a cure for cancer can be solved equally well if large enough sums of money are appropriated. But they are wrong; they do not realize that crash programs require an adequate supply of properly trained men and that such programs are certain to succeed only when the fundamental information upon which a solution is possible is known.

There are many types of cancer and it can never be anticipated that a single medicinal might cure more than one form or possibly a few related forms. Of the patients in which cancer is first diagnosed about one-third are found to have localized cancer, which can often be cured by surgery or x-ray therapy. The other two-thirds have disseminated cancer for which these same treatments are rarely successful. The only obvious approach to treatment of the latter is the introduction of a chemical into the blood stream that will destroy the cancerous but not the normal cells.

No entirely satisfactory method that is both rapid and reliable for determining the effectiveness of a chemical against cancer has been discovered. In spite of this handicap, literally tens of thousands of different organic compounds, selected on a purely empirical basis, have been tested. No breakthrough leading to a cure for one or more forms of cancer has yet resulted.

But during this experimentation, developments of a significant character have been uncovered. After years of failure in the search, differences in the chemical constitution of cancerous and normal cells have been detected. The cancer cells differ from the normal because of minute differences in the structure of the deoxyribonucleic acid, known as D.N.A., found therein. This substance is present in various forms and sizes, though composed of the same basic units, in all living things including bacteria and viruses. D.N.A., the main constituent of the genes, is the principal carrier of genetic information, in other words, the major chemical of heredity.

The enzymatic synthesis of D.N.A has been achieved. Chemists have prepared also many of the units from which the D.N.A. molecule is normally bio-synthesized and many of these same units slightly modified. It is hoped that these latter will be utilized by the cancer cells as building materials for a different D.N.A. which will serve as a destroying agent of the cancer cell. The progress of the cancer problem, though slow, has been significant and it is reasonable to anticipate much more rapid progress and eventual solution.

Let us turn to agriculture and plant life. The most significant contribution the chemist may make to this field in the future is the discovery

of chemicals to accelerate or retard flowering. Experimental evidence indicates that under appropriate environmental conditions, a flower-initiating stimulus is generated in the leaves of a plant and is transported to the buds. Isolation of endogenous flower-initiating factors is and has been a long sought for goal that has not yet been realized.

In most economic plants, the change from vegetative to reproductive growth is determined by the initiation of flowering. Control of this process would provide methods of regulating the character, quality and yield of desired plant products whether they be the foliar parts, the flowers, the fruit and seeds, or certain plant synthates, such as sugar, proteins, and oils. It is entirely conceivable that control of vegetative and reproductive growth could shorten the life cycle of certain annual crops, such as small grains, sufficiently to permit two or even several successive plantings in a single season. The plant's nutrient resources might be channeled away from stems and other non-useful parts and into developing fruit and seed.

Application of gibberillin immediately before and after flowering of grape vines has been found to lead to a superior crop. Timing of the harvest is another potentially important application for flowering regulants. This is in fact accomplished today in the pineapple industry by the use of auxin-like compounds to initiate flowering at any desired time. This effect of auxins is quite specific to pineapple, however.

Likewise, prevention of flowering could have far-reaching consequences in forage-crop production. These crops lose nutritional value rapidly with the onset of the reproductive phase. Satisfactory sugar production depends upon maintaining vegetative growth of the cane or beet until harvest. Hemp crops frequently are ruined by unusual climatic conditions which cause early flowering with resultant short stems and worthless fibers. This could be prevented by flowering inhibitors.

Surplus crops in the United States will not continue indefinitely. In a few decades, with the population increasing at the present rate, maximum production on all arable land will be necessary to supply the people with the generous daily number of calories now taken for granted. Regulation of flowering would provide the most important measure of control over plant growth and permit the maximum effective use of the soil. Indeed the consequences to agriculture would be spectacular.

Initial experiments that may serve to increase our water supplies through chemical treatment of the soil for the plant life have recently been reported. By incorporating in the soil hexadecanol or an analogous higher alcohol the transpiration of a plant is affected; retardation of transpiration up to 40% has been observed. If this could be applied generally, what would it mean? The natural average rainfall in the United States is about 40 inches a year, of which 16 inches is normally

absorbed by plant life and transpired, 14 inches evaporates, and 10 inches is the available water resource that increases ground water or the run off. If the transpiration of plants was to be decreased by 40 per cent, the figures would read, 10 inches loss by plant absorption and transpiration, 14 inches by evaporation and 16 inches left as available water resource, an enormous increase of 60%.

How about adequate meat protein in the future? Poultry raising in recent years has been revolutionized not merely by genetic studies but by the use of properly selected feed and certain growth accelerating chemicals. These have made possible raising a chicken of the same weight in a shorter growth period with the same quantity of feed.

In a recent visit to a Merino sheep station thirty miles west of Canberra, Australia, the owner, who is one of the most successful operators in the country, related that for some years he had been breeding selected rams and ewes with the objective of increasing the number of twin births. By this means the sheep population of his station had been increased by 20 per cent over that normally expected. The gestation period of a sheep varies from 145 to 151 days depending particularly on the breed but in any one breed certain ewes lamb early and some have a shorter lactation period than average. Again by selection it has been possible to find occasionally a ewe that lambs three times in two years. Such advances deserve attention but I predict that the chemist will eventually contribute even more to this field. The modification of normal cycles in animals by appropriate chemicals has already been established. In the future, with proper nutritional control and administration of appropriate hormones or hormone-like substances ewes will be raised that lamb twice a year instead of the normal once. And there is no reason why similar principles may not be applied to cattle raising.

Basic research in organic chemistry, which seeks new knowledge beyond the present frontiers of the science and is the backbone of applied research, is in the hands of academic organic chemists and certain organic chemists in industry. The results lead subsequently to initiation of new and improvement of old technological processes. The scientific significance of basic research is seldom appreciated because the discoveries, no matter how fundamentally important, cannot be described in lay language.

Until the last 25 years, a favorite field in organic chemistry was the study of synthetic methods that would provide more flexible routes to the preparation of desired compounds. The methods have now become sufficiently numerous and so diverse that the major effort of most organic chemists is being focussed on other goals. A more intensive study of known reactions is now a popular subject for research, that is, the mechanism by which molecules react with each other to give a new product, or by which the atoms or groups of atoms in a single molecule will rearrange under certain conditions to a new compound. Such results provide a deeper insight into fundamentals of the subject.

The organic chemist has been extraordinarily successful in the past in determining the constitution of substances found in nature and then synthesizing them. Many organic chemists in all parts of the world are now engaged in the study of the active principles of plants, thousands of which have not yet been investigated. And new substances for study are being extracted from animal sources. The results will supply added information about the processes involved in the chemistry of plant and animal life. As by-products, new types of compounds of chemical interest and others with unique physiological properties that will initiate new chapters in medical research, may well be discovered.

The organic chemist has been greatly aided in his research in recent years by several new tools which permit him first, to separate readily components of a complex mixture, all very similar but not identical in physical properties and second, to determine and confirm the precise arrangement of atoms in molecules. The use of isotopes has permitted a deeper penetration into the chemistry of living matter and provided the opportunity to explore in more detail both biogenetic and chemical processes.

Most organic reactions, whether laboratory or plant operations, can be described as sledgehammer procedures compared with those accomplished in plant and animal life. The plant synthesizes first relatively simple compounds from nitrogen, oxygen, carbon dioxide, and water and then these are converted into a variety of complex substances under very mild conditions. The chemist must usually employ heat, solvents, pressure, catalysts, or combinations of these in order to synthesize compounds that plants and animals can manufacture at ordinary temperatures and atmospheric pressure with extraordinary speed, usually in presence of their own manufactured enzymes that serve as catalysts.

Chemists are striving to learn how to perform reactions in the laboratory under such biological conditions. But to solve this puzzle, much more must be learned about enzymes, their isolation, purification and their chemical characteristics, for these are the key to the duplication of most syntheses performed by plants and animals. Progress may be slow because enzymes are complex proteins occurring usually in mixtures, but the tools are now available to the organic chemist that make possible a more detailed study of such molecules, and significant advances may be expected in the next years.

The organic chemist has hardly broken ground in the study of nucleic acids, those relatively simple chemical compounds that play an essential role in the internal chemistry, growth, and reproduction of the cells; new drugs in this field are almost certain to be realized. The organic chemist is considering the possibility of rectifying somewhat the normal degenerative processes; he is faithfully searching for chemicals to combat viruses; he is wondering whether plants should not be classified on a basis of chemical constituents rather than morphology;

he is exploring the function of chemicals found in plants; and he hasn't forgotten the possibility of improvements in the field of dyes, refrigerants, rodenticides, insecticides, and weed killers.

Time does not permit elaboration of innumerable potential discoveries of the organic chemist. In an address delivered in Philadelphia in 1951 entitled "Man's Synthetic Future," I gave forecasts of things to come. A few that pertained to organic chemistry may be mentioned here; plastics that will breathe and thus replace natural leather for shoe uppers; plant food composed of minerals and fertilizer that can be absorbed through the leaves; chemicals to cause plants no longer to synthesize normally occurring toxic constituents or to synthesize in larger quantities some desirable component; chemicals that will lead to the raising of seedless raspberries, blackberries or cranberries; drugs that will permit the molding of a person physically and mentally (and this last is by no means as remote or fabulous as it sounds). None of these goals has been realized. But progress has been made in fulfilling two other predictions. I suggested as a discovery in the future "antifertility compounds which on addition to the diet will assure a means of controlling the birthrate." Already two such compounds are marketed in the country. They are not the final answer, for in many women they induce annoying side-reactions, they must be taken under carefully controlled conditions in order to assure effectiveness, and they are expensive.

Regarding wool I envisaged, "Half the wool consumed in the United States will be replaced by synthetic fibers within 10 to 20 years . . ." This brought a sharp retort from the wool merchants. But let's review the facts. In 1959, 479 million pounds of wool was consumed in the United States. It may be assumed for convenience that the consumption of wool will increase to 500 million pounds in 1961. Production of synthetic fibers for wool substitution will reach at least 250 million pounds next year and this does not include the millions of pounds of Dacron and Kodel which will be used in blends with wool and therefore are a direct replacement. Thus in nine years, of the total fibers used in articles normally made all of wool one third is synthetic.

Organic chemistry touches every phase of life. I have reviewed a few of the activities of the organic chemist, some of his accomplishments and a few of his problems for the future. I shall be satisfied if I have convinced you that the organic chemist has not been idle in this space age, and indeed that his services are essential to the health, welfare, happiness and progress of mankind.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING—NOVEMBER 16, 1960

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. Wynn Laurence LePage, President, called the meeting to order with approximately 200 members and guests present.

The President stated that the minutes of the October 19, 1960 Stated Meeting will be published in the November issue of the JOURNAL, and will be presented for approval at the next Stated Meeting of The Institute.

The President then announced that at the Stated Meeting of The Institute on October 19, 1960, proposed amendments to the By-Laws (which had been mailed to all Voting Members of The Institute on September 15, 1960) were presented for action. Following a discussion of the proposed By-Laws changes at this meeting, a motion was adopted by the voting members of The Institute to postpone action on the By-Laws revisions until the next Stated Meeting of The Institute. Therefore, a formal notification from the Secretary of The Institute that the proposed amendments to the By-Laws would be presented for action at this meeting was mailed to all voting members of The Institute on November 1, 1960.

The President continued by saying that since the Stated Meeting on October 19, 1960, the By-Laws Revision Committee had met and discussed the objections presented at the October 19 meeting, and that the officers of The Institute had also given serious consideration to this matter. Objections centered on the question of depriving employees, who are members of The Institute, of the privilege of voting. At today's Stated Meeting of the Board of Managers, he said, it was recommended that all amendments proposed should be withdrawn except Article II, Section 3, which relates to Annual Membership, and that this should be modified to restrict members, who are employees, only from service on the Board of Managers.

The President then recognized John Russell, Jr. Mr. Russell said that since the prior meeting on October 19, at which he offered proposed amendments to the By-Laws pursuant to the notice to voting members of The Institute dated September 15, 1960, the matter had been given further consideration by the By-Laws Revision Committee and it is proposed that the only change in the By-Laws be in respect to Article II, Section 3, which pertains to Annual Membership. The changes in the By-Laws as proposed at the last meeting, he said, would have created an employee membership under which employees would have all the privileges of membership except the right to vote and to hold the office of Manager. Under the amendment which he would offer, the employee membership provision would be dropped and it would be made clear in the provision respecting Annual Membership that employees who are members of The Institute will have the right to vote. However, as a matter of sound policy, it is proposed that employees who are members of The Institute will not have the right to hold the office of Manager. Mr. Russell then presented the following resolution:

> RESOLVED, that the resolution offered at the Medal Day Meeting on October 19, 1960 be amended by striking all parts thereof and substituting the following in respect to Article II, Section 3:
>
> *Article II, Section 3*
> *Annual Membership*
>
> ANNUAL MEMBERSHIP. *An annual member, who shall be not less than eighteen years of age, shall be entitled to all membership privileges, including the right to vote and to hold office (except that members who are employees as such term is hereinafter defined shall not have the right to hold the office of Manager), free admission to the Museum and Planetarium, the use of the Library, and the right to subscribe to the* JOURNAL *at a reduced price fixed by the Board of Managers. The members of the family of an annual member, residing in his household, shall be entitled to free admission to the Museum and Planetarium. The dues for annual membership shall be $15.00 a year, except that a member residing fifty miles or more from Philadelphia, a member enrolled as an Associate Member when these By-Laws are adopted, and a member who is in the teaching profession*

on the staff of an elementary school or high school certified by a State Board of Education, a junior college, or a college or university awarding baccalaureate or higher degrees, shall pay annual dues of $7.50.

Within the meaning of this Article II, an employee is any person receiving compensation who comes within the category of an 'employee' of The Institute (or any corporation or foundation under its control through a trusteeship or otherwise) under the Federal Insurance Contributions Act.

Mr. Russell moved the adoption of the resolution. This motion was seconded by Richard T. Nalle. The President then stated, "You have heard Mr. Russell's motion, which has been seconded. Is there a discussion?" After a full discussion, the President requested that the voting members in favor of the motion rise and be counted, and those opposed rise and be counted. He requested the Secretary of The Institute to count the votes. The Secretary reported forty (40) votes cast in favor of the motion and thirty-one (31) votes opposed. The President announced that the resolution as presented by Mr. Russell was adopted.

The President then asked for consideration of the amendment by voting members of The Institute. Mr. Russell moved for formal approval of the amendment as amended in Article II, Section 3, which reads as shown above.

The President called for a second to the motion, which was made. After a full discussion, the President requested that the voting members in favor of the motion rise and be counted, and those opposed rise and be counted. He requested the Secretary of The Institute to count the votes. The Secretary reported forty (40) votes cast in favor of the motion and thirty-four (34) votes opposed. The President then announced that the amendment to Article II, Section 3, was adopted and becomes effective as of this date, November 16, 1960.

The business of the meeting being completed, the President introduced the speaker of the evening, Nathan Cohn, Vice President of The Leeds and Northrup Company, who is responsible for all research, development, engineering and patent activities of this company. Mr. Cohn's talk on "Taming 150,000,000 Horses," discussing the development of the vast electric power networks in this country supplying over 150,000,000 horsepower from hundreds of electric power stations, was ably presented and illustrated effectively, from the simple engine-governor device of James Watt to today's complex "electric brain" control systems. A question period followed Mr. Cohn's talk.

After expressing sincere thanks and appreciation to Mr. Cohn for being with us this evening, the President adjourned the meeting at 9:50 P.M., and invited anyone who would like to see a film Mr. Cohn took in Russia to remain after adjournment. Many members and guests remained to view the excellent film presented by Mr. Cohn.

WILLIAM F. JACKSON, JR.
Secretary

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MATERIALS SCIENCE

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TREATISE ON ORES AND ASSAYING, by L. Ercker. The University of Chicago Press, 1960.

THE ELECTROLYTIC AND CHEMICAL POLISHING OF METALS IN RESEARCH AND INDUSTRY, by W. J. Tegart. 2nd rev. ed. Pergamon, 1959.

THERMOCHEMISTRY FOR STEELMAKING, by J. F. Elliot. Addison-Wesley, 1960.

FLAT ROLLED PRODUCTS: ROLLING AND TREATMENT, edited by T. E. Dancy. Interscience, 1959.

REACTIVE METALS, edited by W. R. Clough. Interscience, 1959.

CONFERENCE ON QUALITY REQUIREMENTS OF SUPER-DUTY STEELS, edited by R. W. Lindsay. Interscience, 1959.

BOOK REVIEWS

PROGRESS IN CRYOGENICS, Volume 2, edited by K. Mendelssohn. 280 pages, plates, diagrams, 6 × 9¼ in. New York, Academic Press, Inc., 1960. Price, $11.50.

If the contributors to a series such as this are to meet the wishes of the editor and are to attempt to "provide critical and up-to-date information in the various branches of cryogenics" and "also to acquaint workers in one field of low-temperature research with the techniques developed in another," then their articles should meet certain fairly obvious criteria. In addition to a discussion of recent developments in a particular field, each chapter should include an introduction describing briefly the scientific and theoretical background for the benefit of the reader not already familiar with the subject matter. A comprehensive list of references should also be provided for those wishing to do more extensive reading. It is, perhaps, too much to expect all the authors in this second volume of "Progress in Cryogenics" to attain these objectives with equal success, but it is certainly to the credit of the Editor that, with one exception, the level of the contributions is as high as it is.

"The Three Level Solid State Maser" by E. O. Schulz-Du Bois provides an example of a well-balanced and lucidly written review article. Without over-emphasis on detail, the introduction provides the reader with the background essential to an understanding of the device. The principal content is nicely balanced between a description of the present state of the art and developments which can realistically be expected. The list of references is extensive.

J. W. L. Köhler, in "The Gas Refrigerating Machine and its Position in Cryogenic Technique," has provided an authoritative discussion of a closed cycle refrigerator capable of operating between ambient temperature and approximately 50°K. Based upon the Stirling cycle of the last century, this machine has already improved the availability of liquid air in many laboratories. The development of larger sizes and the extension of the operating range to lower temperatures will certainly increase its usefulness in future refrigeration problems. The operation of the machine is completely described, both in terms of a thermodynamic analysis and in the details of construction.

Differing aspects of low temperature thermometry are discussed in "The 1958 Scale of Temperatures for the Liquid Helium-4 Region" by H. van Dijk and in "Resistance Thermometers for Low Temperatures" by C. R. Barber. The former provides a detailed account of the evolution of the temperature scale based upon the vapor pressure of liquid He^4 and much of its value lies in the methods used to derive the final temperature scale as well as in the scale itself. In comparison, Barber describes the difficulties involved in the development of a secondary thermometer, satisfactory over the wide range of temperature between 80°K and 4°K, in which some of the "fixed" temperature points have not yet been determined with sufficient precision. A more extensive discussion of resistance thermometry below 4°K would have been valuable in view of the need for a useful secondary thermometer in this area.

In "Methods of Nuclear Orientation," E. Ambler presents a comprehensive review of the experimentatal and theoretical activity in this difficult area of investigation. If any fault is to be found with this detailed and well-documented article, it is that the identification of a technique only by the name of its originator does not simplify the task of a reader not already familiar with the subject matter.

The chapter entitled "The Separation of Deuterium on an Industrial Scale by Low Temperature Distillation" by M. P. Malkov, A. G. Zel'dovich, A. B. Fradkov, and I. B. Danilov provides an interesting companion to "Low Temperature Bubble Chambers" by N. C. Barford. Both are concerned with applications of cryogenic engineering, but while one describes the design of a large production facility, the other analyzes the operation and

construction of a piece of equipment intended as a tool in nuclear research. The chapters are alike, however, in their clear presentation of the fundamental principles involved and their adequate references for further reading.

"The Storage and Handling of Cryogenic Liquids" by G. H. Zenner fails to fit into the pattern set by the other chapters. The article is a wholly descriptive and somewhat repetitious account of the products manufactured by the company with which its author is associated. If the reader is left with the impression that cryogenic engineering is a black art, the paucity of references to published material, other than U. S. and other patents, will do little to alter his opinion.

JAMES NICOL
Arthur D. Little, Inc.

ADVANCES IN THE ASTRONAUTICAL SCIENCES, VOLUME 5, edited by Horace Jacobs. 356 pages, diagrams, 6½ × 10 in. New York, Plenum Press, Inc., 1960. Price, $8.00.

The current volume represents the proceedings of the American Astronautical Society's Second Western National Meeting held in August 1959 in Los Angeles.

This country is most fortunate in having two national organizations whose interest lies in the field of astronautics. The American Rocket Society, through its two journals, makes available to its membership selected papers which may have been read at its meetings. The American Astronautical Society has for the past few years published its complete proceedings in book form. Thus, between the two organizations, the significant contributions by American authors in the field of astronautics find their way into print.

Advances in the Astronautical Sciences, Volume 5, covers six sections of great divergence with, perhaps, the first section on Human Factor the most significant one. Here is found a brilliant exposition on the "Human Factors in Spacecraft Technology" authored by Lt. Commander Richard N. de Callies of ONR. In a concise paper, he sets down the requirements—physiological, psychological and man-machine—which require a thorough investigation to help scientists and engineers in the design of the space craft.

In the second section on Space Mechanics, Control and Guidance, again there is an excellent paper by E. T. Benedikt who writes on the "Scientific Significance of Deep Space Penetration." He shows how deep space probes or "artificial comets" as he calls them can provide answers to fundamental scientific questions on a planetary scale.

"The Magnetic Pinch Engine for Space Flight" by Alfred E. Kunen and W. McIlroy in Section three is a novel paper in which the authors investigate space propulsion and satellite control by adapting the electromagnetic pinch effect to accelerate ionized gas.

Section four deals with Astronautical Systems and Space Vehicle Design while Section five covers Space Communication and Instrumentation. In the latter Section, A. J. Viterbi sets down the "Design Techniques for Space Television." The significant point made in this paper is the design of a TV system to relay a picture from Venus when it is but 26,000,000 miles from the Earth. With a 200-line scan and with 200 elements per tube, the 40,000 bits will take 1.85 hours to be received on the Earth.

The last section deals with Lunar and Planetary Environment. In this section Dr. Robert Jastrow discusses the "Lunar and Terrestrial Atmospheres" in light of the latest results from satellites and probes.

Advances in Astronautical Sciences is recommended to those scientists and engineers who would keep abreast of a fast changing field.

I. M. LEVITT
The Fels Planetarium

DYNAMICS OF THE PATENT SYSTEM, edited by William B. Ball. 449 pages, 6 × 9 in. New York, Central Book Co., Inc., 1960. Price, $12.00.

This book takes the form of discussions of ten critical areas of contemporary patent law which are regarded by 170 patent lawyers assembled in seminar at Villanova University School of Law over a period of ten weeks to be most in need of comprehensive analysis.

Two of these discussions are based upon "the standard of invention in the Patent Office" and the "standard of invention in the courts." Strictly speaking, one might well assume that the standard of invention in both instances is substantially the same. However, immediately we are thrown into two different auras. It is made clear that both tribunals are interested in the question

of patentability of the claims defining invention. In the Patent Office the consideration of patentability of claims is an Ex Parte procedure. Also, the compelling influence of capable patent counsel in a majority of cases has its effect upon the Examiner. It is almost inevitable in close questions of patentability that the Examiner will say, in effect, "Well, O.K., I will allow the claims and leave it to the courts to determine their validity."

So now the patent is before a Federal judge. Prior art cited in the Patent Office and additional prior art cited in the court action are considered Inter-Partes. Such consideration usually proves to be more rugged. Although a patent is presumed to be valid, the patent is not entitled to the presumption of validity as against prior art not considered by the Patent Office. Other defenses having a negative effect upon validity usually develop in litigation. It is no wonder that a surprising proportion of patent claims are held invalid because of anticipation or lack of invention over the prior art.

As stated by one contributor, patent claims before the Patent Office receive rather strict treatment with respect to form, description of the device, composition and process, new uses, completeness and definiteness. That contributor criticizes the Examiners for spending too much time on these technical matters, whereas the most important function of the Examiners should be to find the prior art and then to understand and apply it. Assuming that the criticism is correct, such may well be a reason why so many patent claims are held invalid by the courts.

Prior art material discussed here includes, among other things, (1) priority of invention to be determined between contesting parties, usually in Patent Office interference proceedings, (2) prior knowledge and use of the invention, (3) prior patenting, (4) prior description in a printed publication, (5) prior filing by another, and (6) public use and sale of the invention. Prior art includes a vast public domain storage upon which the public may draw and which also has a limiting effect upon the scope of patent protection a later inventor can procure.

On the subject of patent claims and infringement one of the participants, in an effort to simplify, said all one has to do is read the claim on the accused device. If it applies, there is infringement; otherwise not. Then, by consideration of a number of court decisions, the many exceptions to this simplification are discussed and you "realize that there are 679 fashions in defenses in patent cases."

The subject of contributory infringement is analyzed. This subject can become quite involved, but a sound guide is set forth in United States Code, Title 35:

> Section 271(c) Whoever sells a component of a patented machine, manufacture, combination or composition, or a material or apparatus for use in practicing a patented process, constituting a material part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of such patent, and not a staple article or commodity of commerce suitable for substantial noninfringing use, shall be liable as a contributory infringer.

The contributor, in discussing Section 271(c), indicates that this section has restored balance in the relation between the patent system and the anti-trust laws. He thinks that the evolution of the misuse defense was inevitable in view of the abuses of patents by their owners, that its effect was to bring them back into their proper orbit, "a bit roughly perhaps, but that out of it all, we got a statutory guide."

Another contributor discusses the great need for understanding the subject of misuse of patents. The many ramifications are considered in cases cited, always bringing out the fact that the patentee or licensor, in violating the statute, exacts conditions which go beyond the scope of the patent protection. He emphasizes that the key words of the statute are flexible and will be expanded or contracted according to the importance given to the objective of freeing trade from burdens.

All of the contributors and participants in this seminar have thrown strong and penetrating shafts of light in a review of five years of litigation under the 1952 Patent Act. The cases decided in the early days up through recent decisions are carefully analyzed and the historical perspective brought into focus. The many problems encountered in practice and their solutions are stated in a helpful manner. These lawyers of experience have done a real service in their colorful, interesting, instructive and realistic presentations.

GERRIT P. GROEN
Byron, Hume, Groen, & Clement

PHOTOCONDUCTIVITY IN SOLIDS, by Richard H. Bube. 461 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1960. Price, $14.75.

This book provides a thorough and up-to-date account of photoconductivity in semiconductors and insulators, for the author has spared no effort to illuminate the subject from all possible angles. For that reason, the book goes far beyond what the title indicates—"Photoelectronic Processes in Solids" would be a more appropriate one. It is a rather surprising fact that this book is the first comprehensive treatise in the field, considering that photoconductivity was first observed almost 100 years ago; yet it illustrates the fluidity of a subject which had its greatest advances only in the last fifteen years.

The book may be roughly divided into three parts: An introduction to semiconductor and photoconductor principles, a critical discourse of photoconductivity-, absorption- and luminescence-measurement on practically all materials of interest, and a theoretical part giving a detailed treatment of the various photoelectronic interactions. However, this division is rather vague and one finds theoretical discussions interspersed freely in predominantly experimental chapters to interpret experimental results, and *vice versa*. This makes the book somewhat inconvenient to use as a source of reference for the research worker who is interested in particular materials. Also a list of symbols used at the beginning of the book would improve its readability as a reference work. With the great wealth of experimental results presented in the book, one misses a description of measuring techniques for the various parameters.

After a short historical survey of photoconductivity the basic concepts of semiconductor physics and photoconductivity are developed in the following two chapters. These end with the definition of the all-important trapping and recombination centers, the relation between these, the Fermi level and the demarcation level and a discussion of three basic photoconductor systems.

The next four chapters are more experimental in nature, starting with a review of material preparation techniques, particularly methods for growing single crystals, and a discussion of electrode effects. The compilation in Chapters 6 and 7 of the work on optically induced transitions from impurity and imperfection levels and band-to-band transitions is not confined to photoconductivity, but also embraces luminescence and absorption. More than 100 pages are dedicated to a detailed treatment of photo-response, recombination- and trapping processes in intrinsic and impurity photoconductors.

A concluding chapter deals with related topics such as bombardment induced conductivity, organic photoconductors, photodielectric effect, etc. Considering the generous treatment of other related non-photoconductivity subjects it is surprising that the important photovoltaic effect is dealt with rather shortly.

The book concludes with a survey of uses of photoconductors and finally a very comprehensive literature list of over 1000 references—certainly one of the best features of the book.

ROBERT SEHR
The Franklin Institute Laboratories

ADVANCES IN SPACE SCIENCE, VOL. 2, edited by Frederick I. Ordway, III. 450 pages, illustrations, 6 × 9 in. New York, Academic Press, 1960. Price, $13.00.

This is the second in the Advances in Space Science series and with the publication of this volume this series has come of age.

The editor in his foreword tells us that "Five major areas are covered in the six chapters that comprise Volume 2 of Advances in Space Science. Space physics, tracking, materials, electrical propulsion systems, and altitude control."

Several of these topics have received full coverage in books and the literature but nowhere is there the comprehensive treatment that has been lavished in this work.

Particularly striking to this reviewer is the magnificent treatment given space physics by Dr. Charles P. Sonett of Space Technology Laboratories. The author indicates that this subject . . . "represents a marriage of geophysics and astrophysics to rocket technology." The progeny of this marriage are many and varied. With the tremendous number of scientific investigations going into space (within the next two years single satellites with 50 different experiments will be launched) there should be some place where both the scientist and the engineer can go to obtain a thorough summary of the field.

This exploded summary is furnished by Dr. Sonett. In his construction, this author states the problem, the theoretical approach, the experimental approach and, finally, the conclusions from the reduction of space data.

The author has performed a distinct service to the astronautical field by his contribution. Even in those areas where because of space limitations, the complete coverage was impossible the references accompanying the text permit the serious researcher to further his studies.

The tracking section of this book, (at this moment not of too great significance) will be of increasing use, with the launching of many more satellites and with space getting "crowded," the work of keeping these under surveillance will be brought to a sharp focus.

The third section of this book deals with materials in space. Only with the successful launching of satellites was the question of the behavior of materials in an alien environment emphasized. Under the impetus of the space age a stimulated experimental program must be undertaken to develop or discover the materials that can withstand conditions outside the atmosphere of the earth.

The fourth section on plasma propulsion devices may be a much consulted chapter because of the newness of the concept.

Doctors Ernst Stublinger and Robert N. Seitz contribute a classic chapter on electrostatic propulsion systems. Of particular interest to this reviewer is the historical review of the field and the missions worked out for the use of an ion propulsion system, for the moon, the planets and for deep space.

The last section deals with attitude control of satellites and space vehicles and is written by the ranking authority in the field, Dr. Robert E. Roberson, of Systems Corporation of America.

Advances in Space Sciences, Volume 2, is one of the finest books to appear in 1960 on problems in space that concern both the scientist and the engineer.

I. M. LEVITT
The Fels Planetarium

PHYSICS OF THE UPPER ATMOSPHERE, edited by J. A. Ratcliffe. 586 pages, diagrams, 6 × 9 in. New York, Academic Press, 1960. Price, $14.50.

The upper atmosphere might well be defined as that region which is beyond the realm of the meteorologist, although recent developments suggest that this definition may not continue to remain valid. Phenomena occuring at heights above about 50 miles have been the subject of many different types of investigation for some time. The timing of this book is appropriate in the sense that it provides a rather complete account of the state of our knowledge about this region up to the beginning of the International Geophysical Year, which, of course, represents an abrupt increase in the rate of progress in this rapidly expanding field. This valuable collection of monographs by recognized authorities should serve as an excellent springboard from which to approach the study of the more recent developments which are not included.

After a general introduction in the first chapter by S. Chapman, whose name appears in practically all of the subsequent sections as a significant contributor to the field, there are a number of individual articles representing somewhat diverse approaches to the problem of presenting the type of material which is involved. There are chapters by M. Nicolet (The Properties and Constitution of the Upper Atmosphere), H. E. Newell Jr. (The Atmosphere Studied by Rockets and Satellites), H. Friedman (The Sun's Ionizing Radiations), D. R. Bates (The Airglow, General Character of Aurora, and the Auroral Spectrum and its Interpretation, respectively), H. G. Booker (Radar Studies of the Aurora), J. A. Ratcliffe and K. Weekes (The Ionosphere), E. H. Vestine (The Upper Atmosphere and Geomagnetism), and J. S. Greenhow and A. C. B. Lovell (The Upper Atmosphere and Meteors). Although the styles differ considerably, each provides reasonably complete coverage of the subject under discussion compatible with the available space. The references appended to each chapter are numerous, and probably constitute the most complete bibliography available in a single reference. The book was obviously not designed to serve as a text. The approach is often too encyclopedic for the non-specialist for whom, according to the preface, the book is intended to "provide a survey of a part of physics which has made rapid advances in recent years."

Although *Physics of the Upper Atmosphere* is quite complete, there are certain relevant areas which might well have been included. For example, there is no section devoted to cosmic radiation.

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A final chapter purportedly representing an attempt by the individual authors to "bring their accounts up to date by inclusion of information available up to December 1959, when the book finally went into press," has been added. Designated "Advances during the International Geophysical Year, 1957/1958," there are brief sections written by the authors of some of the other chapters. This furtive attempt falls far short of bringing the subject up to date. It is clearly inconceivable that the many important developments during IGY can be reported in eleven pages. When all of the results from the IGY are finally available, a second volume, which would probably be at least as thick as the present book, will be in order.

All workers in upper atmosphere research will welcome this book as a valuable reference. The reader with only general interest in the branches of geophysics represented herein will be somewhat less enthusiastic.

M. A. POMERANTZ
Bartol Research Foundation

NON-CRYSTALLINE SOLIDS, edited by V. D. Fréchette. 536 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1960. Price, $15.00

This book presents the results of a 1958 conference on non-crystalline solids held at Alfred, New York. It represents an interdisciplinary approach to a subject which heretofore has received limited attention from the majority of scientists engaged in solid-state research.

Subject matter presented falls into four main categories. Interaction of electromagnetic radiation with non-crystalline solids is dealt with in Chapters 1 through 5; electronic structure of non-crystalline solids in Chapters 6 through 8; relaxation processes in non-crystalline solids in Chapters 9 through 12. The remaining chapters are devoted to structure and properties of special systems. Discussion at the end of each chapter serves as an excellent critical evaluation of each author's presentation.

The chapter on "Network Defects in Non-Crystalline Solids" by J. M. Stevels is especially commendable in presenting a systematic study of network defects in vitreous SiO_2.

It is regrettable that the book did not devote a chapter to present-day ideas on glass structure, particularly the vitron theory. Since the book was not intended as a complete text on non-crystalline solids this omission can be tolerated in view of the wealth of information which it supplies in an increasingly important area of solid-state science.

LEIGH JOHNSON
The Franklin Institute Laboratories

THE RADIO NOISE SPECTRUM, edited by Donald H. Menzel. 183 pages, illustrations, 6 × 9¼ in. Cambridge, Harvard University Press, 1960. Price, $7.50.

As a matter of principle, the reviewer has objected to designating as noise both electromagnetic radiation of special interest to scientists on the one hand, and electromagnetic rubbish which interferes with radio communications on the other. This book, consisting of individual chapters derived from papers presented by the respective authors at a Conference on Radio Noise held at Harvard College Observatory in 1958, includes both categories.

The chapters are in the form of either review articles or reports on the specific research program of the author. Discussion among the participants of the conference is also included, as well as a few references, which are generally not intended to constitute complete bibliographies on the subject matter of the chapter. The chapter titles indicate the scope of the contents of this volume. The length of the section varies greatly, ranging from 29 pages on Meteor Scatter by V. R. Eshleman to 3 pages on Interstellar Hydrogen by T. Gold. The others are: The Aurora and Radio-wave Propagation by A. M. Peterson, Ionospheric Scintillation of Radio-waves of Extra-terrestrial Origin by R. S. Lawrence, Electromagnetic Emissions from Meteors by G. S. Hawkins, Whistler-Mode Propagation by R. A. Helliwell, The Radio Spectrum of Solar Activity by A. Maxwell, G. Swarup and A. R. Thompson, Natural Background Noise at Very Low Frequencies by J. Aarons, Solar Whistlers, by T. Gold and D. H. Menzel, Noise of Planetary Origin by B. F. Burke, Correcting Noise Maps for Beamwidth, by R. N. Bracewell, and A Study on Cosmic Radio Noise by D. H. Menzel.

The contributions represent an admixture

of purely scientific problems and subjects of specific interest to the communications engineer. Each chapter follows the very admirable practice of commencing with a definition, in terms which can be understood by non-specialists, of the subject matter to be discussed. The book contains a number of excellent photographs and easily-comprehensible diagrams which considerably enhance its value.

M. A. POMERANTZ
Bartol Research Foundation

BOOK NOTES

STATIONARY PROCESSES AND PREDICTION THEORY, by Harry Furstenberg. 283 pages, 7 × 10 in. Princeton, Princeton University Press, 1960. Price, $5.00 (paper).

In Study 44 of the Annals of Mathematics series, the author's main concern is with sequences derived from Markoff sequences. His thesis—that such sequences are statistically predictable—is developed in nine chapters covering stochastic processes and sequences, stochastic semigroups, Markoff processes and subprocesses, inductive functions and their relation to Markoff processes, continuous predictability and statistical predictability. The final chapter deals with projective inductive functions and prediction. The author's main concern is not to prove theorems, but "to show how certain concepts . . . may be used to systematically analyze various stationary processes and their sample sequences."

AN INTRODUCTION TO THE THEORY OF NUMBERS, by Ivan Niven and Herbert S. Zuckerman. 250 pages, 6 × 9 in. New York, John Wiley & Sons, Inc., 1960. Price, $6.25.

Using a topical rather than an historical approach, the authors present a reasonably complete introduction to the theory of numbers. The first part of the book, on basic concepts, is more detailed than the final chapters, where more specialized material is presented. Intended as a test for a one-year course for seniors or beginning graduate students, the book may be used in a shorter course, since many of the chapters are independent of each other. The problems are varied from simple numerical ones to those dealing with development of theory. Sample subjects treated are the partition function, the distribution of primes, asymptotic density, Diophantine equations, Farey equations and congruences.

STABILIZATION OF FREE RADICALS AT LOW TEMPERATURES, edited by A. M. Bass and H. P. Broida. 110 pages, illustrations, 6 × 9 in. Washington, U. S. Government Printing Office, 1960. Price, $1.50.

The three-year (1956–1959) program in free radical research at the National Bureau of Standards is reviewed in this monograph. Nine papers and an extensive bibliography comprise this volume. One paper describes the organization of the program, seven are papers presented at a 1959 symposium, and the other is a summary of that symposium. Subjects covered include physical and chemical processes in trapped radical systems, experimental aspects of the NBS program, low-temperature chemistry, production of trapped radicals, properties of radical-trapping solids, concentrations of trapped radicals, and interactions between trapped species and the matrix.

SEMINAR ON TRANSFORMATION GROUPS, by Armand Borel. 245 pages, 7 × 10 in. Princeton, Princeton University Press, 1960. Price, $4.50 (paper).

Borel has contributed ten of the sixteen chapters comprising this volume 46 in the Annals of Mathematics Studies; four other authorities complete the roster of contributors —G. Bredon, E. E. Floyd, D. Montgomery and R. Palais. The volume, consisting primarily of notes from a seminar held at the Institute for Advanced Study in 1958 and 1959, gives an exposition of some basic theorems and of results obtained by cohomological methods in the theory of compact Lie groups of transformations. The reader is assumed to know basic theory of transformation groups and algebraic topology.

THERMOELECTRICITY, edited by Paul H. Egli. 407 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1960. Price, $10.00.

These are the Proceedings of the Conference on Thermoelectricity, sponsored by the Naval Research Laboratory, held in September 1958. The book is divided into four sections. The first has four papers and deals with the fundamental concepts in thermoelectricity; the second section has four papers on basic parameters in thermoelectricity; the third includes five papers on chemical and physical properties of materials at high temperatures; and the fourth section has nine papers on measurement of material properties. A conclusion, written by Dr. Egli, synthesizes the ideas and offers valuable guides for the selection of materials at this early stage of development.

PRINCIPLES OF SEMICONDUCTOR DEVICE OPERATION, by A. K. Jonscher. 168 pages, diagrams, 5¼ × 8¼ in. New York, John Wiley & Sons, Inc., 1960. Price, $5.00.

This volume is based on part of a postgraduate course given at Chelsea College of Science and Technology in England. It is intended primarily for those who wish to obtain a better understanding of semiconductor devices based on carrier injection. The treatment does not presuppose any special knowledge of semiconductor physics, provided that the reader is prepared to accept the fundamental facts stated without proof in Chapter 1. These relate mainly to the concepts of electrons and holes in the energy band diagram, mobility, transition processes, etc. From there onwards, the treatment of excess carriers in semiconductors follows its own path with very little further reference to basic theory. In Chapter I, special emphasis is laid on some less familiar aspects of semiconductor theory, such as the question of neutrality and space charge. Chapter II gives a brief review of recombination processes in semiconductors. Chapter III is an attempt at a comprehensive treatment of carrier transport in homogeneous media. Chapter IV gives a complete theory of current flow in *p-n* junctions and junction diodes, a subject which so far appears to have been neglected in textbooks. Chapter V deals with the theory of multi-junction structures in the light of the foregoing treatment. The book closes with a brief discussion in Chapter VI of a subject rarely mentioned despite its fundamental importance—the transport of excess carriers in homogeneous media. This work will be welcomed by a large group of electrical engineers, physicists, and students at the graduate level as an indispensable supplement to the existing semiconductor literature.

DIGITAL COMPUTER FUNDAMENTALS, by Thomas C. Bartee. 342 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1960. Price, $6.50.

This book describes in readily understandable terms the principles of electronic digital computers. The level of presentation is such that it may be used in technical institutes, for undergraduate level courses in universities, in industrial training programs, or for self-study. It is assumed that the reader already has an understanding of the basic electronic and electrical principles which would be covered in a first course in electronics, and a knowledge of elementary algebra. A single area is not concentrated upon, instead, the book deals only with the principles or fundamentals of digital computers, covering the important aspects of the subject in an introductory fashion. Questions are provided at the end of each chapter.

FUEL CELLS, edited by George J. Young. 154 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1960. Price, $5.75.

Based on a symposium sponsored by the Gas and Fuel Division of the American Chemical Society, this small but authoritative book covers the design and principles of operation of several kinds of fuel cells. An excellent introduction (by Liebhafsky and Douglas) leads into the eight technical papers. The closing chapter is a well organized summary of the panel discussion which followed the symposium. Types of fuel cells treated are the hydrogen-oxygen (air) cell with carbon electrodes, the high-pressure hydrogen-oxygen cell, the high- and low-temperature cells, the carbonaceous cell, fuel gas cells, and the molten alkali carbonate cells.

PRINCIPLES OF CONTROL SYSTEMS ENGINEERING, by Vincent Del Toro and Sydney R. Parker. 686 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1960. Price, $14.50.

Intended as a text for seniors or graduate students, this book is a comprehensive treatment of feedback control systems. Prepared originally as classroom notes for use at The City College of New York, the text furnishes an exposition of the various methods of analysis and design and describes their interrelationships. Following an introductory section covering the mathematical background, five main sections deal with these fundamental phases of control systems engineering: Time-Domain Approach; Frequency-Domain Approach; Computer Approach; Root-Locus Approach; and Special Topics (particularly self-adaptive control, with model-reference and impulse-response systems, and nonlinear techniques). Five appendices, an "answers to problems" section, and an index complete the book. Suggested reading lists are included.

FUNDAMENTALS OF SIGNAL THEORY, by John L. Stewart. 346 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1960. Price, $9.00.

This unusual text concerns itself mainly with the mathematical concepts and techniques of value in the analysis of linear and time-invariant systems. It interrelates numerous methods and interpretations, but *not* in relation to specific devices. Eleven chapters cover, for example, vectors, poles and zeros, approximations, operational methods, Laplace transforms, contour integration, Fourier series, and spectra (both discrete and continuous). The book will be useful not only to electrical engineers, but to graduate students in the other physical sciences.

PRINCIPLES AND DESIGN OF PRODUCTION CONTROL SYSTEMS, by Evan D. Scheele, William L. Westerman and Robert J. Wimmert. 369 pages, illustrations, 6 × 9 in. Englewood Cliffs, Prentice-Hall, Inc., 1960. Price: $9.00 (trade); $6.75 (text).

The authors emphasize the design approach to production control systems. They aim their book at developing a scientific approach to the solution of planning and control problems in any type of production or managment activity. Each of the twenty-seven chapters is devoted to an individual major function of production control or to a related management of engineering technique. Sample chapter headings are: Forecasting Techniques, Process Planning and Routing, Tool Control, Loading and Scheduling, Data Processing, Work Sampling, and The Place of Production Control. In an effort to save space, the printer has set too much of the text in type so small that it is difficult to read. This is true also for some of the illustrations, whose lettering is completely illegible.

ELEMENTS OF THE THEORY OF MARKOV PROCESSES AND THEIR APPLICATIONS, by A. T. Bharucha-Reid. 468 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1960. Price, $11.50.

This is a graduate level text and reference in applied probability, useful in several fields of science such as biology, physics, astronomy, astrophysics, chemistry and operations research. Divided into three parts (theory, applications, and the appendices), the book has a two-fold purpose—to provide an introduction to the theory of Markov processes and to give a formal treatment of mathematical models based on these theories. Included in Part I are discussions of branching stochastic processes, the Bellman-Harris theory of age-dependent process, and diffusion processes. Under applications in Part II, the author applies these theories to genetics, nuclear reactors, radiative transfer, queuing, chemical kinetics, etc.

THEORY AND APPLICATION OF FERRITES, by Ronald F. Soohoo. 280 pages, diagrams, 6 × 9 in. Englewood Cliffs, Prentice-Hall, Inc., 1960. Price: $12.00 (trade); $9.00 (text).

Putting equal emphasis on the physical and engineering aspects of ferrites, this new text may be used either for a college course or for independent study. Part I on theory covers properties of matter in the solid state, dielectric and magnetic properties of ferrites, the permeability tensor, measurement, propagation of electromagnetic waves (both in infinite anisotropic media and through anisotropic waveguides). In Part II the author

(of MIT's Lincoln Laboratory) treats ferrites below microwave frequencies, longitudinal and field-displacement devices, cutoff phenomena, transversely magnetized and nonlinear ferrite devices.

THE PLANETARY EQUATORIUM, translated by E. S. Kennedy. 267 pages, illustrations, 5¼ × 8¼ in. Princeton, Princeton University Press, 1960. Price, $7.50.

One of Princeton's Oriental Studies, this book consists of the facsimile pages of a 15th century Persian manuscript, facing pages of translations of these reproductions, and a lengthy Commentary by the translator. The original manuscript is a description of two computing instruments used to determine solar, lunar and planetary true longitudes as predicted. This instrument represents the peak of the development of such instruments, for it was the only equatorium with which the determination of planetary latitudes was attempted. The translation sounds in spots like a high school student's version (in that it is so literal), for the translator has numbered his translated lines to correspond with the lines on the manuscript; this procedure results necessarily in stilted English. However, the scholarly Commentary, which occupies about a third of the book, is well written and adds considerably to the growing history of analog computers.

LECTURES IN THEORETICAL PHYSICS, Volume II, edited by Wesley E. Brittin and B. W. Downs. 483 pages, diagrams, 6¼ × 9 in. New York, Interscience Publishers, Inc., 1960. Price, $9.00.

This volume represents a series of eight lectures delivered at the second annual Summer Institute for Theoretical Physics held at the Department of Physics at the University of Colorado, June 15 to August 21, 1959. The papers included are: "Invariance Properties in Elementary Particle Physics," by Abdus Salam; "Symmetry Laws and Elementary Particle Interactions," by J. J. Sakurai; "Hypernuclei and the A-Nucleon Interaction," by B. W. Downs; "The Classical Electron," by F. Rohrlich; "Many Body Problem in Quantum Mechanics," by N. M. Hugenholtz; "Present Status and Problems in the Theory of Beta Decay," by J. Hans D. Jensen; "Aspects of Abstract Field Theory," by M. Dresden; and "Quantum Mechanical Amplifiers," by W. E. Lamb, Jr.

ANALOG AND DIGITAL COMPUTER TECHNOLOGY, by Norman R. Scott. 522 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., Price, $12.75.

This book is an outgrowth of a course that has been presented at the University of Michigan since 1952. It is intended for beginning graduate students in electrical engineering or for seniors who have completed their undergraduate programs in mathematics and in electronics. The first four chapters treat the d-c. electronic differential analyzer, which is loosely referred to as the "analog computer," and the last seven chapters treat the digital computer. In each of these two major parts, the computer is first dealt with as a tool, and methods of using it to solve problems are introduced; then its design is approached from an engineering point of view, and the appropriate engineering technology is introduced. The book is intended primarily for use by electrical engineers, and this double approach to each class of computer arises from the fact that the electrical engineer's relation to computers is unique, since he alone both uses and designs them.

CERMETS, edited by J. R. Tinklepaugh and W. B. Crandall. 239 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1960. Price, $9.50.

A survey of oxide and carbide-base cermets is thoroughly discussed in this volume. Twenty-three contributors, each a recognized authority in the field, cover the fundamental aspects, forming and processing, testing and applications of these increasingly important high-temperature materials. The well-known and widely-used alumina and titanium carbide-base cermets are used as model systems in the description of properties and typical fabrication methods. In addition, considerable space is devoted to the physicochemical aspects of cermets in order to provide the reader with the background information he needs to understand the relationship between the proper selection of materials and the fabrication of cermets with required properties. Sections dealing with applications have been specifically designed to acquaint the research

worker with present limitations and future possible uses of cermets. This book will be of interest to the metallurgical, ceramic, aircraft, chemical and electronic industries.

FOOD CHEMISTRY, by Lillian Hoagland Meyer. 385 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1960. Price, $6.75.

This work is intended primarily as a text in food chemistry for undergraduate students in home economics, food technology and chemistry. It should also prove useful as a reference book for research workers in these fields as a unified picture of foods from a chemical standpoint is herein provided. The primary emphasis is on the composition of foods and the changes that occur when they are subjected to processing. The author has kept in mind undergraduates who have had a course in organic chemistry; however, an effort has been made to provide necessary background chemistry and sufficient explanations for students to proceed without additional references. A chapter on food additives and the appendix on permissible food additives are special features of this text that provide up-to-date information on this vital topic. At the end of each chapter are bibliographical references to aid the reader who wishes to investigate further the respective areas of food chemistry.

PUBLICATIONS RECEIVED

ENGINEERING MECHANICS: STATICS AND DYNAMICS, by Irving H. Shames. 656 pages, combined volume, diagrams, 6 × 9 in. Englewood cliffs, Prentice-Hall, Inc., 1960. Price, $9.75.

BASIC ELECTRICAL MEASUREMENTS, by M. B. Stout. Second edition, 571 pages, illustrations, 6 × 9 in. Englewood Cliffs, Prentice-Hall, Inc., 1960. Price: $11.65 (trade); $8.75 (classroom).

FREE AND INEXPENSIVE EDUCATIONAL AIDS, by Thomas J. Pepe. 289 pages, 5½ × 8 in. New York, Dover Publications, Inc., 1960. Price, $1.35 (paper).

FOOD FOR AMERICA'S FUTURE, by Ethyl Corporation. 167 pages, diagrams, 5½ × 8 in. New York, McGraw-Hill Book Co., Inc., 1960. Price, $3.95.

TABLES OF OSCULATORY INTEGRATION COEFFICIENTS, by Herbert E. Salzer, Dexter C. Shoultz and Elizabeth P. Thompson. 43 pages, 8½ × 11 in. Convair-Astronautics, 1960. No price. Paper.

INTRODUCTION TO GEOLOGY, by Alfred Livingston, Jr. Revised edition, 55 pages, diagrams, 8½ × 11 in. Palo Alto, N-P Publications, 1960. Price, $3.00 (paper).

MICHELSON AND THE SPEED OF LIGHT, by Bernard Jaffe. 197 pages, illustrations, 4¼ × 7¼ in. New York, Doubleday & Co., 1960. Price, $0.95 (paper).

THE UNIVERSE AT LARGE, by Hermann Bondi. 154 pages, illustrations, 4¼ × 7¼ in. New York, Doubleday & Co., 1960. Price, $0.95 (paper).

PASTEUR AND MODERN SCIENCE, by René Dubos. 159 pages, 4¼ × 7¼ in. New York, Doubleday & Co., Inc., 1960. Price, $0.95 (paper).

ACCELERATORS, by Robert R. Wilson and Raphael Littauer. 196 pages, illustrations, 4¼ × 7¼ in. New York, Doubleday & Co., Inc., 1960. Price, $0.95 (paper).

FLAME-SPRAYING OF ALUMINA

The basic principles involved in the flame-spray process of coating metals with alumina are being investigated by the National Bureau of Standards for the Air Force. D. G. Moore, of the Bureau's ceramic coatings laboratory, is directing the investigation. Potential uses of the heat resistant coating produced by this process include the thermal protection of jet and rocket engine components, and regulation of temperature within space vehicles. One of the determinants of coating structure is particle velocity; to study this variable, a rotating-disk velocimeter was developed.

Of the three current methods for applying coatings to metal by particle impact—namely, flame-spray, detonation, and plasma-jet—the flame-spray technique offers the advantages of mobility and relative ease of operation. Although the coating of parts by flame-spraying has been practiced for many years, the application of alumina by this means is a relatively new development.

In flame-spraying alumina, two types of oxy-acetylene guns known as the "powder gun" and the "rod gun," are used to melt and propel the particles. In the powder gun, finely divided alumina is fed into the combustion zone, producing a continuous stream of particles. The rod gun is fed by a $\frac{1}{8}$-in. rod of sintered alumina, and air is introduced at the exit nozzle to increase particle acceleration. It was observed that the rod gun normally produces bursts of particles, rather than a continuous stream.

The experiments have shown that the strength of the bond formed between alumina and iron increases exponentially with increase in surface roughness of the substrate. In order to measure bond strengths, metal strips were roughened to various degrees by different blasting treatments and mounted between two knife edges so that a 0.05-in. length of each strip projected beyond the tips. Both sides of this projecting portion were spray-coated to a thickness of 0.010 ± 0.002 in. The force required to shear the coating from the strip was then determined by pulling the coated section through the gap between the knife edges. The sprayed particles of alumina did not adhere to metal strips that had been polished. The measured bond strengths for surfaces that had undergone severe roughening were many times greater than for surfaces that had received only mild roughening treatment. Also, bond strengths for coatings formed with the rod gun were greater than for those formed with the powder gun.

A rotating disk velocimeter[1] was developed for determination of particle velocities. This device consists of a 16-in. metal disk, with a narrow metal strip attached by means of posts which support it at a known distance from the surface of the disk. A glass slide is attached to the disk in a position where it will be partially shielded from the sprayed particles by the narrow metal strip. When this slide is sprayed with the molten alumina, the strip

[1] "Velocity Measurements of Flame Sprayed Alumina Oxide Particles," by D. G. Moore, W. D. Hayes, Jr. and A. W. Crigler, Wright Air Development Center Report 59-658, Part I.

creates a "shadow" in the layer of particles that adhere to the slide. The slide is first sprayed while the disk is at rest, and then when it is rotating at known speed. The displacement between the two "shadows" formed on the slide is a function of the particle velocity. The particles from the rod gun had a measured peak velocity of 566 ft/sec, and those from the powder gun, 145 ft/sec.

No direct method was devised for determining the temperature of the small, fast-moving particles; however, the appearance of the particles after impact gave an indication of their consistency at the instant of contact. Glass slides were sprayed while maintained at various distances from the guns, and the particles that adhered were examined microscopically.

From the patterns produced by the particles when they deformed upon impact, it was determined that at 2 in. from the powder gun most of the particles were molten only on the outside; at 4 in. practically all of the droplets were completely molten; and at 6 in. only the cores were molten. Particles that are completely molten at the time of impact adhered more readily than the others. The rod-gun particles, because of their higher velocity, flowed more on impact than did the powder-gun particles.

The thermal properties of a material influence the flow of molten particles immediately following impact. When the adhering particles cool more slowly as they do on glass, flow continues for a longer time than when the cooling rate is very rapid, as it is on platinum. Cooling rates were calculated for a thin layer of molten alumina striking the surfaces of various materials at room temperature. The initial cooling rate of molten alumina on glass (2050–1800°C.) was computed to be 34,000°C./sec, and on stainless steel, 800,000°C/ sec. Experiments with heated platinum substrates indicated that the ratio of alpha and eta alumina in solidified particles is dependent upon the quenching rate, and that the formation of the metastable eta form is favored by rapid quenching.

When a particle strikes glass it cools less rapidly than when it strikes metal, thus allowing more time for a chemical bond to form. To indicate whether slower cooling would also give a chemical bond with metal, augmenting the mechanical bond, a strip of iron was coated with porcelain enamel, which in turn was covered with an 0.0003-in. layer of nickel. The ceramic substrate effectively lowered the cooling rate of the sprayed particles, but the bonding was not improved.

On glass good bonding occurred whether the surface was rough or smooth, but on iron the bond strength was substantially increased by roughening the surface. These results suggested that the bond between the alumina coating and glass substrate is largely chemical, but that the bond formed between flame-sprayed alumina and metals is principally mechanical in nature.

CURRENT TOPICS

Optical Reading Machine.—Both typed and printed business information can now be read for the first time directly into a computer memory for high-speed data processing. This major advance in computer technology has been announced by International Business Machines Corporation with the introduction of its 1418 optical character reader. The new solid-state unit reads data printed in widely used styles on paper or card documents, at a rate of 480 characters per second. As many as 400 documents a minute may be read. The printed data are automatically translated into machine language for direct input to an IBM 1401 computer.

The 1418 reads numbers printed ten characters to the inch in a standard IBM type by 407, 408, or 409 accounting machines, the 1403 printer, or an electric typewriter. It can also read numbers in the elongated 407 type style, commonly used by credit card imprinters, which is seven characters to the inch. In addition, the 1418 can be equipped for mark-reading—in which vertical markings made with ordinary pencil or dark inks represent specific information determined by the format of the document.

The optical character reader handles documents of various sizes and thicknesses. Forms can be anywhere from $5\frac{7}{8}$ to $8\frac{3}{4}$ in. wide by $2\frac{3}{4}$ to $3\frac{3}{4}$ high. Their thickness can vary from that of bond paper to IBM card stock. Any printed documents within these dimensions—premium notices, imprinted charge slips, telephone bills, tax notices, coupons, and continuous-card forms, for example—can be used as direct input to the 1418-equipped 1401 system.

As the documents feed into the 1418, they are separated and aligned, one document at a time. Each form then feeds individually onto a revolving drum, where it is held flat by a vacuum. As the drum revolves, the complete surface of the form passes under a lens system.

The standard IBM 1418 contains one optical reading station, which will read a single type style from any line on the document. Available optionally are either a second reading station or a mark-reading station. With the second reading station, two lines can be read in one pass of a document through the machine. These lines can be in the same or different type styles.

The 1418 employs an exclusive scanning method which recognizes a practical range of print quality. The characteristics by which each number is identified are contained within the solid-state circuitry of the reader. The light image of a character is converted into electrical impulses which are compared and matched with internal logic patterns. Numerical characters are individually recognized in this way and transferred one at a time to the magnetic core storage of the 1401 system.

Once in storage, the data from the printed forms can be processed and the results produced as punched cards, magnetic tape, or printed reports by the 1401. The forms from which the data were read are fed by the 1418 into its appropriate sorter pockets.

While the 1418 is reading, the 1401 can perform independent functions,

such as a magnetic tape to printer operations. The magnetic tapes prepared on the 1418-equipped 1401 can also be used for input to larger IBM data-processing systems.

The 1418 reader can be used with any Model C, D, or E 1401 magnetic tape data-processing system. It is available in two models—Model 1 with three sorter pockets and Model 2 with thirteen sorter pockets. When not in use with the 1401, the 1418 Model 2 can be used for independent optical sorting of printed forms and cards.

The 1418 optical character reader for the 1401 will be manufactured at IBM's Endicott, New York, plant. Initial deliveries of the 1418 are scheduled to begin in the first quarter of 1962. It can be installed in the plant or on a 1401 in the user's office.

Polyethylene Antioxidants.—The discovery that certain classes of organic chemicals can behave like carbon black in protecting polyethylene from thermal degradation has been announced by scientists from Bell Telephone Laboratories, Murray Hill, N. J. Mrs. M. A. Worthington and Dr. W. L. Hawkins presented data to the American Chemical Society, meeting in New York City, to show that a number of compounds containing alternating unsaturated bonds provide excellent thermal antioxidant properties in combination with previously reported sulfur-bearing compounds.

The activity of the combination greatly exceeded that which would have been expected from consideration of either compound by itself. This property, in which the total protection exceeds the sum of its parts, is called "synergism." Previously, only carbon black showed this synergistic effect with sulfur antioxidants.

Carbon black is widely used in polyethylene formulations as a light screen for outdoor use. Telephone cable sheath, for instance, would rapidly lose its strength unless protected from light in this way. Although carbon black is very effective against light degradation (photo-oxidation), it provides relatively little protection against heat. Thus, the addition of thermal antioxidants is generally necessary.

Bell Laboratories recently discovered a large group of sulfur-containing organic chemicals which acted as effective thermal antioxidants when combined with carbon black. This is in contrast to conventional antioxidants which generally lose their effectiveness in this combination. Effective sulfur compounds include thiols, disulfides, and some thio-ethers.

The fact that these sulfur compounds are far more effective in the presence of carbon black than in its absence stimulated research into the properties of carbon black which are responsible for this synergistic effect.

In their experiments, Dr. Hawkins and Mrs. Worthington regarded carbon black as granules of carbon with reactive chemicals adsorbed on the surface, but as a highly complex, unsaturated organic chemical, with reactive surface groups.

From modification and removal of these active groups, it appeared that the effectiveness of carbon black arose from the extensive conjugation, or alternating single and double bonding between carbon atoms. This led to attempts to duplicate the carbon black action with simpler conjugated organic compounds. The effort was successful, and a number of large fused-ring hydrocarbons such as tetracene, pentacene, and perylene have proved to be highly effective thermal antioxidants when used with the sulfur-containing compounds.

Perylene, for example, a compound containing five fused six-membered

rings with alternating double bonding, is completely ineffective as an antioxidant by itself. So is 2-naphthalenethiol, which contains two fused rings with a sulfur-hydrogen group. Polyethylene containing 0.1 per cent of each compound in combination, however, was protected from rapid auto-oxidation under accelerated test conditions for more than 2000 hours, in comparison with 500 hours for the best commercial protectants. Oxidation resistance was investigated over a wide temperature range. Data showed that stability improved at lower temperatures at a greater rate than previously considered antioxidant systems.

Other compounds which show similar bonding arrangements are equally effective in combination with sulfur antioxidants. Diphenoquinones (six-membered rings linked with double bonds, with oxygen atoms at either end) are effective, as are similar compounds containing nitrogen instead of oxygen (quinonediimines).

Although there is no intention to replace carbon black as a light screen in exterior applications, a basic understanding of the mechanism of carbon black activity would be of great benefit in improving existing polyethylene formulations. (High carbon black mixtures are becoming increasingly important in large structures and shapes.) The non-black antioxidants could however be used in transparent formulations for indoor use, where light oxidation is not a problem.

Vibrational Compaction for Ceramic Fuels.—Harmonic tones pouring from an instrument that resembles a giant "hi-fi" set may not be pleasing to a musician, but the notes are real music to the ears of scientists working in Hanford Laboratories' Ceramic Fuels Development Operation.

Unlike the normal hi-fi set which is used to play recordings, the "speaker" in this equipment serves as a shaker or vibrator for packing nuclear powder materials into fuel elements for atomic reactors at the Atomic Energy Commission's Hanford plant, operated by the General Electric Company. And it happens to be an extremely efficient method of packing the powder to more than 90 per cent of the theoretical density.

A look at the equipment's potential in the manufacture of fuel elements tends to mellow the blaring tones generated by its 24,000-watt power amplifier system. A hi-fi fan familiar with the average home-owned 20 to 25 watt amplifier system capable of rattling the windows and occasionally rattling the neighbors, can multiply that by about 1000 times to get an idea of the tremendous vibrations this set can produce.

Fabricating nuclear fuel elements by this new process is aptly called Vibrational Compaction and is described as a rapid, simple and extremely flexible method of simultaneously compacting and cladding ceramic fuel materials.

Fuel element fabrication costs, which are presently an obstacle to developing economical nuclear power sources for generating electricity, are expected to be reduced substantially as a result of the efficiency of this new Hanford development.

Tubes up to 8 ft. long which serve as the cladding or jacket for nuclear fuel element materials are attached to the vibrator, and nuclear fuel powder poured in from the top can be compacted to more than 90 per cent of the theoretical density in about three minutes.

The loud speaker or vibrator portion of the equipment consists of a moving coil which is alternately at-

tracted and repelled by a large electromagnet to deliver a thrust of up to 5000 pounds force.

Housed in a sound absorbing box on the floor, the vibrator is capable of shaking the fuel element at frequencies between 5 and 5000 times per second. Nearly the entire frequency range is used for the compaction of each tube.

In fabricating Hanford fuel elements with the vibrator, accelerations greater than 100 G's, or 100 times the acceleration due to gravity, have been applied to eight-foot-long tubes during vibrational compaction without any dimensional changes or adverse effects on the tubes.

Fuel rods with walls as thin as .005 in. (slightly thicker than this sheet of paper) have gone through the vibrational compaction process without damage. The use of walls this thin has definite advantage because of the fuel element's improved ratio of nuclear fuel to cladding material. The wall soaks up fewer of the reactor's neutrons which are necessary to the fissioning process.

The feasibility of vibrational compaction was established by General Electric scientists at Hanford by fabricating 19-rod cluster fuel elements for the Plutonium Recycle Test Reactor which is now being constructed for experimental work in peacetime applications of atomic energy.

Fuel rods for this reactor are eight feet long and about one-half inch in diameter. After the shakedown process is completed, end caps are welded on the tubes and they are tested and inspected prior to assembling into the 19-rod assemblies. No surface conditioning is required since the rods undergo no dimensional or structural changes during vibration. Massive, nested tubular fuel assemblies also have been fabricated. Preparations are being made for fabricating, by remote handling techniques, fuel elements containing highly radio-active, "recycled" uranium oxide from the PRTR and other reactors.

The value of a fabrication process is measured by the performance of the product, and irradiation tests of Hanford's vibrated fuel elements in several reactors have revealed excellent performance and stability, which adds to the quality of Hanford's "scientific symphony."

Creep-Rupture Behavior of Alloys. —Correct selection of alloys designed to function at space-age temperatures has been greatly simplified by a device developed by a metallurgist at Union Carbide Metals Company. Using a master diagram and any three of the four main design variables (stress, temperature, material, and rupture time or creep rate) the fourth variable can immediately be determined. The diagram lists eleven commonly used high-temperature alloys.

This finding is but one result of recent investigations into the creep-rupture behavior of alloys near the melting temperature, an increasingly difficult problem encountered in manned and unmanned flight. Conducted at the Metals Research Laboratories of Union Carbide Metals Company, Division of Union Carbide Corporation, the work was sponsored by the Army Ballistic Missile Agency, Huntsville, Alabama and carried out by M. Korchynsky, a research metallurgist at UCM's Laboratories.

Part of the study was concerned with the derivation of analytical equations describing the time to rupture (or minimum creep rate) as a function of stress and temperature. Success in this work resulted not only in a diagram which graphically displays these

relationships but several other important determinations.

For example, it was shown that the equations which describe the relationship between rupture time (or minimum creep rate), stress, and temperature can be used to predict rupture times much longer than those determined by actual experimentation. As a matter of fact, investigations have verified that creep-rupture tests which take only minutes to complete can, in some instances, be used to predict rupture times of several hundred hours' duration.

Study of the analytical equations also showed that the parameters required to relate them could be obtained by direct experiment, using a limited number of critical tests. This fact points the way to the interesting possibility of drastically reducing the experimental testing program, for a complete evaluation of creep-rupture behavior of an alloy could be obtained from only 5 to 7 tests.

Other experiments were conducted on iron-, nickel-, and cobalt-base alloys in the 1150° to 1450°C. temperature range, with the upper limit only 20° to 40°C. below the melting temperature of these alloys. A highly reliable testing procedure was employed in which specimens were heated by their own electrical resistance. Since surface temperature and elongation distribution along a gage length were determined experimentally, the creep rate of the specimen could be measured with a high degree of reproducibility. Results of the creep-rupture experiments should be of value in preliminary screening of standard materials for very high-temperature service.

Another phase of the study evaluated the effect of various metallurgical factors on high-temperature creep. Alloys were selected which typify a variety of base metals, crystal structures, alloying additions, microstructures, and both stable and nonstable phases. Analysis of the results has provided a foundation for the rational design of new alloys intended for service near their melting temperatures.

Solar Demonstration Kit.—A compact, inexpensive demonstration kit that shows solar energy at work is now available from Central Scientific Co., Chicago. The kit, especially suited for instruction in the sciences, consists of 12 silicon solar cells, a small motor and a three-blade propeller. When exposed to the sun, the solar cells convert the sunlight into electricity that powers the motor and turns the propeller—illustrating the conversion of solar energy into electrical energy and thence into mechanical power. The propeller can be replaced with pulleys or gears for other demonstrations of this conversion.

The Solar Demonstration Kit is manufactured by the Semiconductor Division of Hoffman Electronics Corp., El Monte, Calif. Hoffman has named Central Scientific Co., Chicago, as a distributor of the kit.

The solar cells in this kit are the same kind that Hoffman supplied to power the radio transmitters in the Vanguard I, Explorer VI, Explorer VII and Pioneer V satellites. The radio of Pioneer V has transmitted on solar power from a record 15 million miles out in space. Vanguard I's transmitter has been at work since March 17, 1958—more than 20,000 hours.

Like the solar cells in the satellites, the cells in the new Cenco-Hoffman Solar Demonstration Kit never wear out; they don't even lose their maximum power performance. So there's practically no parts-replacement problem with the demonstration kit.

Cost of the Solar Demonstration Kit, Cenco Catalog No. 81090, is $18.25. For additional information about it, write to Central Scientific Co., 1700 W. Irving Park Road, Chicago, Ill.

Vacuum Indicator-Controller for Process Control.—A new thermocouple-vacuum-gage indicator-controller that is especially adaptable to close-tolerance control systems has been announced by General Electric. Through use of a time-proven vane-and-coil type control mechanism, the instrument offers closer, more reliable control and more accurate indication than is possible with contact-type models. It is intended for a wide range of vacuum system applications, including electronic tube evacuation, metalizing, distillation, heat treating, and others.

The instrument can initiate control on either increases or decreases in pressure. Control point is adjustable over the entire calibration range, which is one to 1000 microns.

The controller portion of the G-E instrument, instead of using contact points, employs a small metal vane on the pointer which passes between a pair of sensing coils when the pointer reaches the set-point. This activates an oscillating circuit which in turn de-energizes the controller relay. The "contactless contact-making" arrangement does not interfere with free movement of the pointer.

Advantage of this system, company engineers said, is that it offers excellent indication and control tolerances around the setpoint. They said the new instrument will be far more adaptable to high-accuracy process control than are contact-type controllers, whose contact magnets tend to affect freedom of the pointer at critical points.

The instrument is connected to vacuum systems by a 6-ft cable and ⅛-in. diameter standard pipe thread gage tube. Latter can also be attached using a standard O-ring seal.

Electric Analog Models Simulate Ground-Water Systems.—Engineers and scientists of the Department of the Interior's Geological Survey have put together an ingenious electronic device capable of predicting the effects of long-term pumping from an underground reservoir and describing water movement through earth materials. It will also predict how long a given local water supply will last as more and more users move into a community.

Geological Survey's "Analog Model Analyzer" consists of two units: one, a network of electric resisters and capacitors built into a scale model of a given aquifer as visualized by geologists; the other, an electric pulse generator which simulates water "head" changes such as occur when a well is pumped, coupled with an oscilloscope which translates head changes into a drawdown graph on a fluorescent screen.

How to accomplish accurate measurements and make predictions has challenged geologists and engineers for many years. Hydrologists have known for a long time that the ground-water supplies of the world far exceed surface-water supplies in bulk. Geologists well understand the forces of nature responsible for creation of the rock and earth materials constituting underground basins or reservoirs. But how can one measure something which in its natural state can be neither seen nor touched?

The solution arises from the near-perfect analogy between the laws describing the flow of electricity and the laws describing the movement of ground water. A group effort by five Geological Survey employees in Phoenix, Arizona, resulted in development of the model analyzer. Once

the local geologic environment is simulated electronically, a rapid analysis of ground-water flow problems can be made.

Today the Survey has a Hydrologic Analog Model Unit established in Phoenix to provide services to its district offices in most of the 50 States. The unit is "open for business" and prepared to apply electric analog model techniques to the solution of complex ground-water-flow problems under study by the Survey.

New Type Chemical Molecules.—The formation of an entirely new class of chain-like molecules has been discovered by Dr. E. Wasserman of Bell Telephone Laboratories. These compounds, tentatively named "Catenanes" from the Latin word for "chain," are composed of large interlocking rings which are otherwise unbonded. Physically, a model of the molecules is more similar to a linked chain than are the presently so-called long chain molecules.

In the synthesis of the new compound, long straight molecules with a reactive group on each end were mixed with a large ring compound. In a small fraction of the mixture, a straight line molecule would be expected to thread through the center of a ring, simply through mixing. When these straight molecules are closed into rings through reaction of the end groups, the threaded molecules form an interlocked pair with the ring molecules already present. Statistical analysis indicates that a few percent of these interlocked pairs should exist.

The presence of about 1 percent of these linked rings was demonstrated by chromatographic elution techniques. Subsequent degradation and identification of component fractions through the use of deuterium tags proved the existence of the new "compound."

Further work is under way, aimed at producing enough of the catenane to isolate a pure sample and measure its properties.

Studies of molecular models indicate that a "doughnut" of carbon atoms must contain at least 20 atoms, or segments, before the "hole" is large enough to permit the through-passage of another molecule. In the experiments reported by Dr. Wasserman, the rings contained 34 carbon atoms, as did the straight line molecules.

In the interlocked form, one of the rings was a hydrocarbon (containing only hydrogen and carbon atoms) while its partner was an "acyloin," with a carbonyl oxygen attached to one carbon plus a hydrogen-oxygen (hydroxyl) group on the neighboring carbon.

The demonstration of the existence of simple linked pairs introduces the possibility of more complex interlocked systems, although the existence of previously postulated long, chain-like silicone and phosphorous-nitrogen polymers appears unlikely. It does, however, appear possible that three ring systems can exist in detectable quantities. These could be linked together in several ways.

Such interlocking forms will require chemists to take another look at the word "molecule," since the separation of the rings requires the breaking of a chemical bond, even though the rings themselves are not joined by any chemical bonding.

These new molecules also force consideration of an entirely new type of isomerism, based on topology, in addition to the well known structural and geometrical isomerism. For example, a mixture of the two separate ring molecules, even though nonlinked, is actually an "isomer" of the interlocked pair, since the chemical bond-

ing between atoms is identical in both forms.

Another example of topological isomerism occurs in single, large cyclic compounds containing 50 carbon atoms or more. These can exist in large simple rings, or in a ring with a simple knot, according to Dr. Frisch. Extremely complicated mathematical shapes, such as Moebius strips, are also possible through various combinations of cross-linking, interlocking, and knotting.

From analogy with other types of isomerism, topological isomers could conceivably differ in some of their physical properties, such as viscosity and melting point. Chemical reactions of this species would probably not differ markedly from well known reactions, except for possible steric and specific interactions between rings and conformational differences.

Irradiated Fish Tags.—Atomic radiation, a tool that can allow science to find a needle in a hay stack, is about to help biologists trace fish through the broad Pacific ocean. The secret life of the tiny herring will soon be less secret, thanks to Hanford's huge production reactors. General Electric workers at the Atomic Energy Commission-owned Hanford atomic plant are irradiating 9000 fish tags in one of the reactors for use by the U. S. Fish and Wildlife Service. The tags will be injected into herring released in Alaska.

When the tagged fish are caught by commercial fishermen, miles away and years later, the irradiated tags will perform their function. At the reduction plant, the herring are moved along on a conveyor at a high rate.

When a tagged fish speeds by, a sensitive radiation detection instrument will activate machinery which will remove the tagged fish from the conveyor.

The tag can then be examined to determine when and where the fish was tagged and released. Without the irradiated markers, it would not be practical to tag so small a fish as a herring. Detecting the tags would be too time consuming and expensive to be worthwhile. The atom-age tags solve the problem. Hanford experts advise that the tags are "hot" enough to alert sensitive cannery counters, but have not been given enough radioactive exposure to harm the fish, even over a long period of time.

By learning more about the migratory pattern of herring, biologists will be better able to increase the nation's supply of this important animal feed and oil source.

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